MDS AeroTest

Design of Hydraulic Loading Room Layout and HVAC

Mech 4860 Engineering Design
Final Design Report

Prepared for: Jordan Ilott
Cameron Whitton

Faculty Advisor: Kathryn Atamanchuk

Prepared by: Team 22

Mark Yakimishen ______________________

Samantha Parker ______________________

Philip Ariano ______________________

Byron Wiebe ______________________

Executive Summary

This report presents details of the process taken to reach the final conceptual design of a hydraulic loading room to be implemented at the MDS AeroTest GLACIER facility. This room is used to house equipment that provides the hydraulic flow necessary to simulate hydraulic loads on partner OEM gas turbine engines. As per consultation with the client, the current configuration of the hydraulic loading room required implementation of HVAC and spill containment measures in conjunction with an enhanced layout plan to create a safe and efficient work environment for MDS AeroTest personnel. The deliverables presented in this report include conceptual engineering drawings, HVAC calculations and analysis (Appendix A), a trade-of study comparing the generated concepts (Appendix B), and relevant research/literature.

To address this problem, the design team first analyzed the needs, target specifications, and constraints of the project. The problem was then broken down into the following sub-systems: layout, heating, ventilation, spill prevention, and spill containment. Concepts for each sub-system were generated using concept screening matrices, concept scoring matrices, and individual weighted criterion used to rank each concept. Concepts that ranked highest were developed further in the final design.

The layout of the hydraulic loading room positions equipment in such a manner that frees up nearby floor space to allow more room for MDS AeroTest personnel to complete maintenance and HLU installation as required. The HVAC system has been designed to incorporate an insert duct heater into the ventilation ducts which emits heat into the workspace via three high-sidewall diffusers. Air pollutants are captured by three local exhaust hoods placed in front of the spill containment basin. The heating and ventilation systems combined, provide 12 air changes per hour (as per the Skydrol LD-4 MSDS) and 88,250 Btu/hr to maintain room comfort in the Northern Canadian climate. The spill containment systems control hydraulic fluid spills through a perforated floor into a custom-gradient basin and is pumped out into an oil drum for recycling. The spill prevention system uses an auxiliary bleed-line to drain the pressure, suction, and case drain steel lines leading to the engine test stand. Hydraulic fluid can be drained through a diagnostic-tee into a 200-Litre storage tank in under 3 minutes per line. Fluid that is captured in this system can be re-used for future tests by transferring this fluid to the primary storage tank in the room. The design for each system meets each of the client needs and complies with the constraints of the project, therefore the conceptual design herein stated has been deemed acceptable.

Table of Contents

List of Figures

List of Tables

1. Introduction

This section of the report provides a brief background of our client, MDS AeroTest and the GLACIER facility they manage. This section will also contextualize the project in terms of objectives, requirements, technical specifications, constraints, limitations and client deliverables.

1.1. Client Background

MDS AeroTest manages and maintains the GLACIER ice testing facility, shown in Figure 1, which is a joint-owned venture between Pratt & Whitney and Rolls Royce. This facility is located in Thompson, Manitoba, where they utilize the cold Northern Canadian temperatures to mainly perform ice certification testing on gas turbine engines, although they have the capacity for many other tests, such as endurance and thrust testing.

Figure 1: GLACIER gas turbine testing facility [1].

For some performance tests MDS AeroTest utilizes hydraulic equipment, which is housed in a mobile trailer near the test stand, shown in Figure 1. The mobile trailer is called the hydraulic loading room and is the primary focus of this design report.

1.2. Project Definition

MDS AeroTest has requested a conceptual design of an improved hydraulic loading room at the GLACIER testing facility. The hydraulic loading room contains a hydraulic loading unit (HLU), which is used to supply hydraulic fluid to the test engine, a hydraulic fluid storage tank, a polishing skid used to clean the hydraulic fluid and a glycol skid, which is used for cooling the hydraulic fluid during tests. The hydraulic loading room is not used frequently; only some tests require hydraulic fluid, which is specified by the OEM.

The current configuration of the equipment in the room is shown in Figure 2. The OEM supplies a specific HLU for each test, therefore the figure does not contain the HLU. However, the HLU would normally be located between the hydraulic fluid storage tank and the glycol circulation skid.

Figure 2: Current hydraulic loading room [2]

An upgrade to the room was required by the client due to the space being dysfunctional and potentially dangerous for the employees to perform maintenance on the equipment and to perform test set up and tear down procedures. Consultations with the client yielded four main categories of issues that required improvement in the upgraded design. Each issue was used to develop the needs of the project. A summary of the issues of the current hydraulic loading room are presented in Table I.

TABLE I: HYDRAULIC LOADING ROOM ISSUE SUMMARY

Category	Issue
Layout	Limited space around equipment to perform maintenance, connect & disconnect hoses
	Hose routing is a tripping hazard

	HLU was difficult to install into the room (polishing skid and storage tank must be removed and replaced)
Spills	Draining hydraulic fluid from the lines leading to the test engine results in spills on the floor, equipment, and employees, which is hazardous and requires lots of time for cleaning
	Hydraulic fluid lines are drained into small troughs or trays that do not always successfully collect the entire spill volume
Ventilation	Current ventilation is insufficient to exhaust vaporized hydraulic fluid and off gassed fumes to safely work in the space without respirators
Heating	Current heating system is comprised of baseboard heaters located just above the floor. Hydraulic fluid spilled on the heaters is vaporized, which is hazardous

The full list of needs developed from the issues and requirements from the client are shown in Table II. The "I" column represents the rank of importance, which is ranked from one to five, where one is the least important and five is the most important.

TABLE II: PROJECT NEEDS

#	Need	I
1	**Equipment should be easily interchangeable and accessible**	5
1.1	HLU must be easy to install and remove	5
1.2	HLU must have 360-degree access for maintenance and setup	4
1.3	Hydraulic hoses should be easily removed and interchangeable depending on HLU unit	4
1.4	Equipment should be easily accessible for regular maintenance	4
2	**Spill containment and collection strategies must be in place for HLU room**	4
2.1	Hydraulic fluids and glycol must be collected within HLU room to prevent outside spills	3
2.2	The containment system shall ideally separate the spilled materials to allow for reprocessing or for required environmental disposal	2
2.3	Debris including dirt, snow, and water, should be avoided in oil retention solution	2

#	Need	I
2.4	Spill containment system needs to be easy to clean after the collected fluid has been drained	3
2.5	Hoses need to be kept from sitting in fluids	2
3	**Spill Prevention strategy needs to be in place**	3
3.1	Spill prevention needs to be able withstand high pressures	2
3.2	Solution should reduce the amount of hoses and connections that need to be removed/attached	4
4	**The climate in the hydraulic loading room must be suitable for employees**	3
4.1	Hydraulic loading room must have a heating system that will not re-vaporize hydraulic fluid	2
4.2	Temperature in the hydraulic loading room must be adjustable	3
5	**Hydraulic loading room needs proper ventilation**	4
5.1	The HVAC system must be able to evacuate warm air	4
5.2	Workspace ventilation must be able to evacuate harmful contaminants from the air	4
5.3	Air quality needs to be suitable for employees to work in	3
6	**HLU room needs to be safe for employees**	4
6.1	Floor must be clean from spills	4
6.2	Floor needs to be slip resistant	4
6.3	Floor needs to be clear of hoses to mitigate tripping hazard	4
7	**Proposed hydraulic equipment must be compatible with aviation grade hydraulic fluid**	3
7.1	Materials should be resistive to chemicals used in hydraulic loading room	2
8	**HLU room needs to be mobile**	1
8.1	Room can be transported with the use of a crane	1
8.2	Equipment in HLU room should be safe from damage during transportation	1

Important constraints and limitations in order to ensure the viability of our final design are presented below. Please note that there is no particular order to the constraints listed.

1. **The final design report must be completed prior to December 4th.**
2. **The high-pressure line to the gas turbine must not experience large changes in back pressure.**

   The pipes feeding and returning hydraulic fluid to the gas turbine positioned above the room are running at high pressures and sudden flow restrictions risk spiking these pressures. Such spikes risk damaging the gas turbine or other system elements.
3. **The size of the room is limited by the space on site and the need to be transportable by crane.**

   The current location of the hydraulic test room is on a concrete pad, adjacent to a water purification room and the turbine mounting structure. This location slightly limits the maximum size of a room that could be placed without expanding the concrete pad and increasing pipe lengths. Furthermore, the size is constrained by the possible need to relocate the room for future site configurations. Our preliminary estimates indicate that the room should be no larger than 35 feet by 12 feet.
4. **The design is limited to materials that can resist the corrosive environment caused by aviation grade hydraulic fluid.**

   Hydraulic fluid spills are a frequent occurrence in the current hydraulic loading room configuration. As such, our design must consider all materials that come into contact with the fluid, such as hoses, valve internal components and elements of the spill collection system. Materials must be chosen such that hydraulic fluid spills and normal operation do not lead to dangerous degradation of the system elements.
5. **The design must accommodate testing with the various hydraulic loading unit sizes and configurations.**

   A wide array of engine types from two different manufacturers are currently tested at the MDS AeroTest facility. This also translates to many different types of hydraulic loading units. The dimensions of these units change for each engine type with some units being approximately two meters long. This means that the hydraulic loading room must be versatile enough to accommodate different sized units and occasionally cater connections to extra-large external units.

The viability of the final design will require metrics with which its functionality can be assessed. The metrics generated by the team to assess the final design are available in Table III. The “I” column indicates the importance of that metric, ranked from one to five, where one is the least important and five is the most important.

TABLE III: TECHNICAL SPECIFICATIONS

#	Need #s	Metric	I	Units	Marginal Value	Ideal Value
1	1, 1.1, 1.3	Relative time to install and remove HLU	5	Minutes	15 - 60	15
2	1.2, 1.4	Space encompassing each piece of equipment	4	Feet	2 - 4	4
3	1	Number of hoses to disconnect for HLU swap	4	Number	4 - 6	4
4	2.1	Capacity of spill containment system	3	U.S. Gallons	20 - 55	55
5	2, 2.2, 3	Cross-contamination between glycol & hyd. fluid	2	Percent	0 - 10	0
6	2.3, 3.2, 7	Amount of contaminants in fluid (fluid cleanliness)	2	NAS 1638 particle count per AS4059F	7	7
7	1.4, 2.4, 2.5	Time required to clean equipment	3	Hours	1 - 5	1
8	2.5	Surface area of hoses sitting in the fluid	2	Square feet	0 - 1	0
9	3.1	Pressure rating of components on high pressure hydraulic lines	2	Psi	3000 - 5000	5000
10	4.1	Surface area of heating element exposed	2	Square feet	0 – 3	0
11	4.2	Adjustable temperature and ventilation	3	Yes/no	No	Yes
12	5.1	Heat supplied to hydraulic loading room	4	Btu/hr	73500	88200
13	5.2	Ventilation Rate	4	Air changes per hour	6	10

#	Need #s	Metric	I	Units	Marginal Value	Ideal Value
14	5, 5.2, 5.3	Air quality/amount of contaminants in the air	3	mg/m^3	3.08 - 12.52	3.08
15	4, 4.2, 5, 5.3	Comfort Level index	3	Subjective	1-5	5
16	6, 6.1, 6.2	Area of floor affected by spill	4	Square feet	0 – 2	0
17	6.2	Coefficient of friction, wet floor	4	lbf/lbf	0.4 – 0.6	0.6
18	6.2	Coefficient of friction, dry floor	4	bf/lbf	0.4 – 0.6	0.6
19	6.3	Area of floor affected by tripping hazards	4	Square feet	0 - 1	0
20	6, 6.1, 6.2	Lost time hours	3	Hours	0 - 3	0
21	7, 7.1	Corrosion rate	2	µm/year	40 - 160	40
22	8, 8.1, 8.2	Transportability (via crane)	1	Yes/no	No	Yes

It should be noted that each system will use the above technical specifications as design criteria in the development phase. However, due to the nature of this project, many of the technical specifications can only be validated if proper prototyping and testing is completed following the completion of the design phase. Measurable technical specifications will be revisited following the design details to summarize which values have been achieved in our final design.

Our team's objective is to evaluate and select an optimized conceptual design that meets the client's needs outlined in Table II. Thorough consideration of the constraints and limitations will also be conducted to ensure a successful design and client satisfaction. To deem this a successful project, the final report must contain the following deliverables:

- Conceptual engineering drawings
- Calculations and other analysis to support HVAC specifications
- Trade-off studies supporting the selected designs
- Relative research and any important literature

Since the client requires a conceptual design, the budget was not considered a deliverable and the drawings and research must be of quality that will convey the basic design.

1.3. Design Methodology

This project had five interconnected but vastly different systems for the team to research and develop. The team determined that splitting the sections into the corresponding topics would be the most efficient way to complete this project. As a result, the project was split into five different areas: layout, spill prevention, spill containment, heating, and ventilation. The team generated a list of needs, provided in Section 1.2, based on the information supplied by the client and further research. Client consultations highlighted the issues with the current hydraulic loading room, as well as other improvements that the client envisioned in the new design. The team then generated five concepts for the layout, ventilation, and heating systems, and six concepts for the spill prevention and spill containment systems. Criteria were established from the list of needs, and specific weights for each criterion was established based on their importance relative to other criterion used to evaluate the same system. The decision matrices for layout yielded a clear winner referred to as 'Layout B' detailed in section 3.1. For this reason, only one layout was carried forward to the final design phase. All other concepts were evaluated using the weighted criteria and the two designs that scored the highest were selected to be further analyzed before selecting and developing the final design for each system. Table IV displays the summary of the rankings for the two concepts from each system carried forward to the final design phase. Appendix B contains the detailed design and initial concept screening process, which includes the weighted decision matrices and scoring matrices.

TABLE IV: SYSTEM CONCEPT RANKINGS FROM CONCEPT GENERATION PHASE

System	Concept	Score /5
Spill Prevention	Quick connect couplers on hydraulic lines	3.80
	Auxiliary bleed line off main pressure line	3.91
Spill Containment	Perforated floor over drainage basin	3.22
	Spill pallets under equipment	3.91
Heating System	Radiant wall heating	4.55
	Furnace heater	4.67
Ventilation System	Dilution ventilation with force-air heating	4.36
	Local exhaust ventilation	4.42

2. Concept Selection

The concepts generated for each sub-section of our design were assessed using a thorough concept screening and scoring process using a list of weighted criteria. For the ventilation, heating, spill containment, and spill prevention sub-sections of our design, two concepts were chosen as possible candidates. The layout concept did not need further development and thus was not included in this section. The following sub-sections give a brief overview of the concepts that were selected during the concept design phase and a description of how the final concept was selected.

2.1. Ventilation Concepts

Two main concepts for the ventilation system were carried forward from the concept development phase of this project to the final design phase. These concepts were general industrial ventilation (also known as dilution ventilation) and local exhaust ventilation. Section 2.1.1 and 2.1.2 provide a brief introduction to these systems and present which design will be further developed for the final design.

2.1.1. General Industrial Ventilation

General industrial ventilation, also known as dilution ventilation, supplies clean, uncontaminated air into the space of interest in order to dilute the concentration of the contaminated particles in the air. Dilution ventilation is particularly suitable for areas and situations where contaminants are more of an irritant than pose serious health risks.

2.1.2. Local Exhaust Ventilation

Local exhaust ventilation (LEV) uses high velocity flow to remove contaminants near the source of generation. LEV systems provide the most level of protection from harmful contaminants, however, their performance can also be affected by poor air flow patterns and regions of high velocity air near the LEV hoods.

2.1.3. Ventilation Concept Selection

The team decided to implement the dilution ventilation strategy to supply air into the space and utilize a local exhaust system to exhaust air out of the trailer. The two systems will work together in order to remain within the recommended exposure limits of 5 mg/m_3 for tributyl phosphate [3], which makes up 55-65% of Skydrol LD-4 hydraulic fluid by concentration. The selected ventilation system is a dilution ventilation system that uses local exhaust hoods to remove contaminated air from the space instead of a return air grille. Local exhaust ventilation was selected because of the system’s ability to extract contaminants at the source, thus decreasing the amount of air required to dilute the remainder of the air to remain under maximum exposure limits.

2.2. Heating Concepts

The two concepts that were nominated from the concept generation phase of this project were radiant heating and a furnace heating system. These systems were selected for further analysis to determine which system would be best for the hydraulic loading room. During the final design phase, further consultation with the client and Dr. Robert Derksen, an HVAC professor at the University of Manitoba, led to changing the concepts of the heating for the room. Radiant heating was considered a good concept as it has a low temperature heating surface to prevent vaporization of settled hydraulic fluid. However, in-wall or in-floor radiant heating was determined to be an expensive investment into a room that is not frequently used. Additionally, maintenance on a hydronic or electric in-wall or in-floor heating system would require deconstruction of the trailer to access the heating system, which would cost time and money. Radiant heating panels were considered instead of the in-wall/floor radiant heating, however the largest capacity panel that was found provided only 800 Watts of heating. Since 800 Watts was not sufficient and using multiple panels was not optimal, the design team decided to re-evaluate the forced air space heater that was discussed previously in the conceptual design phase. The forced air space heater offers higher heating capacity and would be simple to replace and maintain. The idea of a furnace heating system was retained; however, it was decided to use a fan and an in-duct heating coil to achieve the same effect. A small sized in-duct heater was chosen to ensure that the limited space in the room was not devoted to heating equipment.

The total heating capacity that is required of the heating system is 88,200 Btu/hr or 26 kW. The required heating system capacity was calculated from the heat losses through the building envelope via conduction and infiltration and from the energy required to heat the outdoor air to an acceptable indoor working temperature of 41˚F (5˚C). For further detail in the heating load analysis, refer to Appendix A Section 3. The two heating system concepts were evaluated on the ability of the system to supply the required heat to the space, which satisfies project need 4, found in Table II. Additional to the providing the required heat, the preferred heating system must also be thermostat controlled (need 4.2), prevent vaporization of hydraulic fluid (need 4.1), be constructed of materials that are compatible with aviation grade hydraulic fluid (need 7.1) and be easily accessed and maintained (need 1.4). The following sections give a brief overview of what the system is and how well it is suited for the hydraulic loading room.

2.2.1. In-Duct Heating Concept

The in-duct heating system is an electric heating element inserted into a rectangular duct that is incorporated into the ventilation system. The insert duct heating element is easily removed from the ductwork to perform maintenance as required. There are many different brands that offer in-duct heating elements, which are all very similar in design and available in a range of heating capacities. The evaluation of this concept was based on Thermon model DIF insert duct heating element [4]. Insert heating elements from Thermon have capacities that range from 2.5 to 62.5 kW, thus have the capacity to output the required heating load of 26 kW. The heating element is completely sealed in the ductwork therefore it is unlikely for hydraulic fluid to come in contact with the heater and be re-vaporized. The material of the ductwork can be constructed from aluminum, which is compatible with aviation grade hydraulic fluid [5]. This heating system meets all the requirements set out by the project needs, thus was the selected concept to further develop for the final design.

2.2.2. Forced Air Space Heater Concept

The forced air space heater is a stand-alone heating system mounted on the ceiling, which has the capability of thermostat control. This heating unit is not enclosed in ductwork therefore there is a possibility of hydraulic fluid coming in contact with the heating elements. Since the heater would be ceiling mounted, the chance of hydraulic fluid spilled on the heating elements is low however, there is still the hazard of vaporized hydraulic fluid settling on the heating elements and being re-vaporized when turned on.

Through research on different heating units, there are many different brands that offer a large variety of heating capacities. King brand heaters were used to evaluate this type of heating system [6]. King offers electric forced air space heaters ranging from 0.95 to 34.5 kW, which would satisfy the required heat capacity. Similar to the in-duct heating system, this space heater would be easily removed for replacement or maintenance, if required. While this system meets all the requirements set out at the beginning of this section (except for the possibility of re-vaporization), this system has the possibility of countering the ventilation flow of the room. If the air flow of the space heater is high enough and does not align with the ventilation air flow, there is a chance for hydraulic fluid vapours to be recirculated back into the breathing zone, which is to be avoided. Since the ventilation is important in keeping the room safe to work in for the employees, the unknown effect of the two different air streams makes this system not as ideal as the in-duct heating concept. Due to the discussed reasons in this section, the forced air space heater was not selected for further development for the final design.

2.3. Spill Prevention Concepts

The main goal of the spill prevention system is to decrease the total amount of fluid that is spilled in the hydraulic loading room. Two solutions were generated so that further analysis of each concept could be provided within this report. Possible solutions included the implementation of hydraulic quick couplers and an auxiliary bleed line.

2.3.1. Hydraulic Quick Couplers

The hydraulic quick couplers would be installed in areas where hydraulic hoses were frequently disconnected due to assembly and disassembly of the HLU. This includes the pressure, suction, and case drain lines located at the hydraulic loading cabinet. If properly selected and installed, hydraulic fluid would be retained in all hydraulic hoses and spills would be prevented due to the locking mechanism of the quick coupler assembly.

This concept, as shown in Figure 3, was further discussed with the client and the following points led us in the direction to eliminate hydraulic quick couplers as a viable candidate:

- Hydraulic quick couplers have been investigated in the past and would often fail due to material incompatibility between the internal hydraulic seals and Skydrol LD-4
- Due to the complex nature of these quick couplers, the supplier would have to create custom components as aviation-grade hydraulic quick couplers are not readily available in the sizes that are required for the client's application
- Specialized quick couplers increase exponentially in cost compared with their conventional counterparts.

[redacted]

Figure 3: Hydraulic quick couplers

2.3.2. Auxiliary Bleed Line

Another viable option was the auxiliary bleed line, shown in Figure 4, which would route a separate hydraulic hose in parallel with the hydraulic lines that were frequently disconnected.

[redacted]

Figure 4: Hydraulic diagnostic bleed-line

This parallel line would be coupled with a ball-valve which could be opened and closed to redirect the flow of fluid to a storage tank. The client expressed interest in this concept and believed that an auxiliary bleed line could effectively reduce the amount of hydraulic oil that would need to be drained into the hydraulic loading cabinet. Due to this positive feedback from the client, the team decided to develop the auxiliary line concept further.

2.4. Spill Containment Concepts

The preliminary design phase yielded two possible design concepts for the containment of fluid spills in the hydraulic loading room. The two design options are spill pallets and perforated floor grates. The following sub-sections discuss these two design concepts and select a final concept to further develop for the final design.

2.4.1. Spill Pallets

Placement of spill pallets under key equipment like the glycol skid and hydraulic loading unit would allow for collection of fluid spills in the highest spill likelihood areas. These pallets could be removed with pallet jacks and forklifts then subsequently drained after testing. This option is appealing because spill pallets can be linked together to create a variety of custom layouts and sizes to accommodate for various possible hydraulic loading unit dimensions. These pallets are also inexpensive, and their high-density polyethylene construction maintains an excellent compatibility rating with Skydrol LD-4 hydraulic fluid [5].

Discussions with the client revealed concerns with the implementation of spill pallets. The first of concern was that spill pallets would need to extend beyond the equipment dimensions in order to successfully capture spills caused from line disconnections. Spill pallets extending beyond the equipment would take up valuable walkway area and require the operators to reach in a bent position to perform hose connections. Such a technique is awkward for the human body and may pose an ergonomic hazard. A second concern raised was that the intense vibrations cause by the hydraulic loading unit during operations may lead to instability and shifting of the equipment or the pallets leading to a potential failure. Furthermore, the hydraulic loading unit is on rollers which means that the high-density polyethylene grate would need to be substituted for a custom grate made from an alternate material to avoid potential shearing caused by vibrating point loads.

2.4.2. Perforated Floor Grates

Installation of perforated floor grates allows spills to drain into a spill collection basin. This basin could then be periodically emptied into barrels for disposal using a hand pump. This method requires gradients beneath the grate to collect and contain spilled fluids. Such a system requires a larger capital investment than spill pallets however it provides less obstruction to the operators.

In contrast to the spill pallet concept, a perforated floor grate system would provide a level surface and not obstruct operator access to hose connection points. Such a system would also not be as susceptible to vibrations and shearing due to the point loads that the hydraulic loading unit rollers represent. The modular nature of spill pallets offers the benefit of fluid separation and decreased likelihood of debris contamination over floor grates; however, this benefit does not outweigh the aforementioned drawbacks. For this reason, the perforated floor grate design will be carried forward to the final design phase.

3. Final Design Details

Details of the design have been broken down into five categories: layout, heating, ventilation, spill prevention, and spill containment. A final render has been provided to show how each system has been integrated with the layout of the hydraulic loading room as shown in Figure 5.

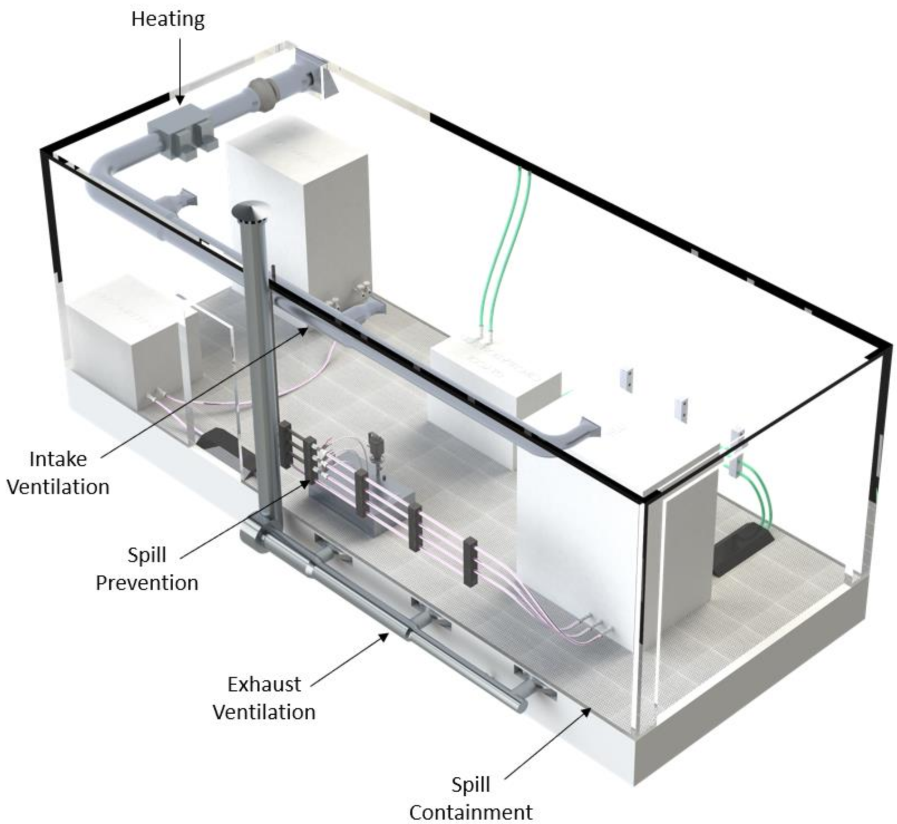


Figure 5: Final hydraulic loading room conceptual design

The overall layout of the re-designed hydraulic loading room organizes the equipment in such a manner that allows the client to simply install the HLU through the large door without any further maneuvers, as discussed in Section 3.1.1. Once placed inside, the hydraulic hose from the polishing skid can easily be coupled to the HLU by removing this hose from the hose management guides, as discussed in Section 3.1.2. After the filtered hydraulic fluid is pumped into the HLU, hoses from the hydraulic loading cabinet and glycol circulation skid can be removed from the wall and installed on the HLU. During testing operations, the ventilation system will ensure the supply of clean air, and removal of pollutants as discussed in Section 3.2. A heating system will provide a comfortable climate for the workers present in the room as discussed in Section 3.3. After the required tests have been completed on the gas turbine engine, hydraulic hoses from the test stand can be drained without any major spills as per the spill prevention system in Section 3.4. Spills within the hydraulic loading room that are considered inevitable will have been collected in the spill containment system to provide a safe working environment, as discussed in Section 3.5.

The following sections will be used to explain, in more detail, the subsections of the final design that were developed from the concept selections in Section 2. The details include a description of each concept, the components that are used in each concept, and how each system will be integrated into the hydraulic loading room to directly meet the client's needs as per Table II. It should be noted that the designs presented are conceptual and, as such, formal engineering drawings have not been included.

3.1. Layout

This section describes the details of the room construction, the layout of the equipment, and the hose management for the room. These aspects of the room have been considered to increase space around the equipment, improve ease of HLU installation into the room and decrease tripping hazards due to hoses.

3.1.1. Equipment Layout

The preliminary design phase led to the selection of an equipment layout configuration depicted in Figure 6.

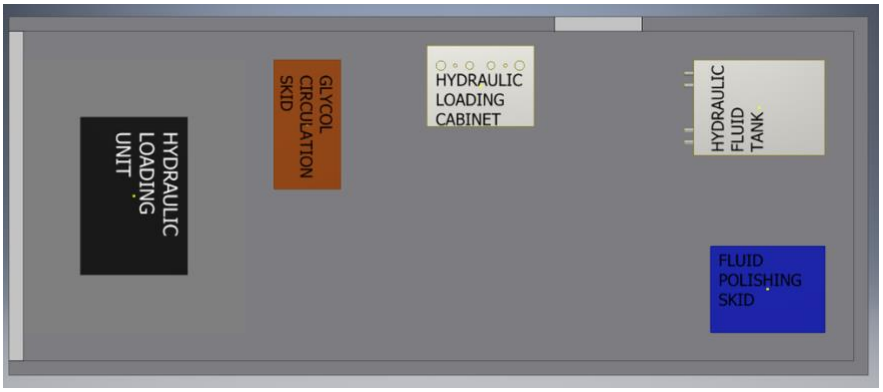


Figure 6: Layout B

Since Layout B is the equipment configuration carried forward to the final design phase, some equipment orientations and parameters have changed. The first of these changes was the removal of the hydraulic loading cabinet in favor of a portable reservoir that receives post-test hydraulic fluid by way of a bleed-line, as discussed in Section 3.4. Another change from layout B was the relocation of the glycol skid to the opposite wall. This was done in the interest of keeping all the hydraulic fluid and glycol hoses running on their own separate respective lengthwise walls. This goal of having all the hydraulic fluid lines running on the same wall as the loading cabinet meant the polishing skid and retention tank also had to swap positions. The client requirements for this project only outline the need for a conceptual design however a floor layout plan drawing was created with suggested equipment positioning dimensions. This layout plan is shown in Figure 7.

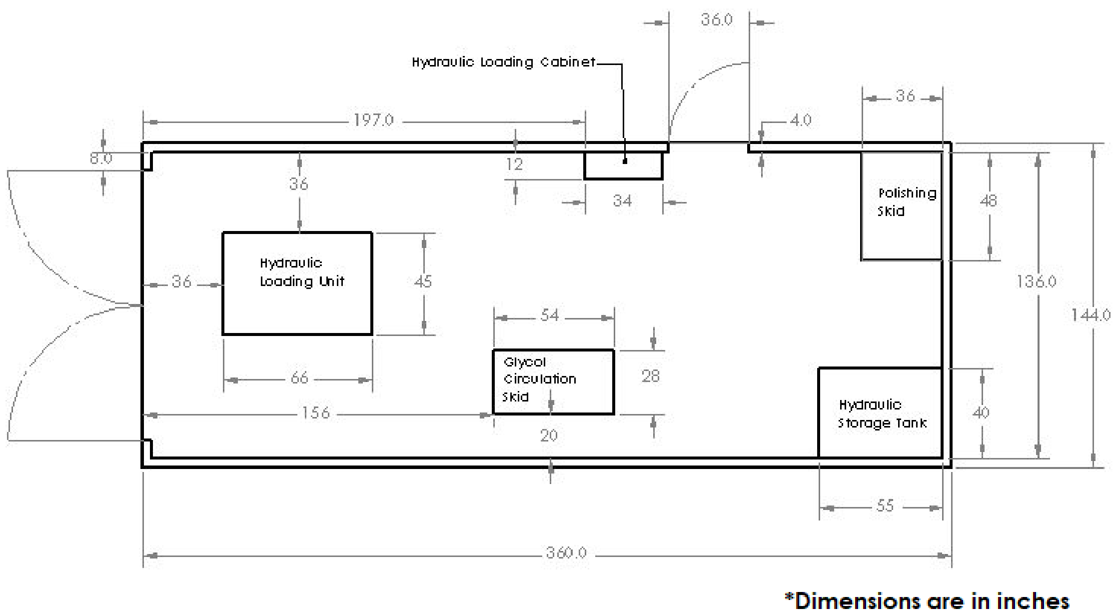


Figure 7: Hydraulic loading room layout plan

The layout plan shown in Figure 7 contains suggested dimensions for equipment positioning that could be adjusted slightly for operator preference. It should also be noted that HLU dimensions are subject to variation based on the turbine being tested. The thought process behind the equipment placement was as follows:

- The hydraulic loading unit maintains a minimum 36-inch corridor of access on all sides. This was deemed the minimum dimension to allow for hose bend radii and operator access to the hose connection ports (needs 1.2 & 1.4).

- The glycol skid was placed opposite the wall of the hydraulic loading cabinet. This was done in part to separate the glycol and aviation grade hydraulic fluid hoses and allow them to follow their own respective lengthwise walls. A distance of 20 inches from the wall was selected to allow for glycol hose bend radii to reach the HLU.
- The hydraulic fluid storage tank's sides and rear section are not frequently accessed so it was placed against the wall.
- Only access to the front connection ports of the polishing skid is required on a frequent basis so it was placed close to the walls in a similar manner as the hydraulic fluid tank.

3.1.2. Hose Management

The hose management system design for the hydraulic loading room had two primary objectives. The first of these was to increase safety for operators by reducing the tripping risk posed by hoses crossing the walkway. The second objective was to make the testing set-up and tear-down process easier and more efficient. The hose routing diagram for the final room design is shown in Figure 8.

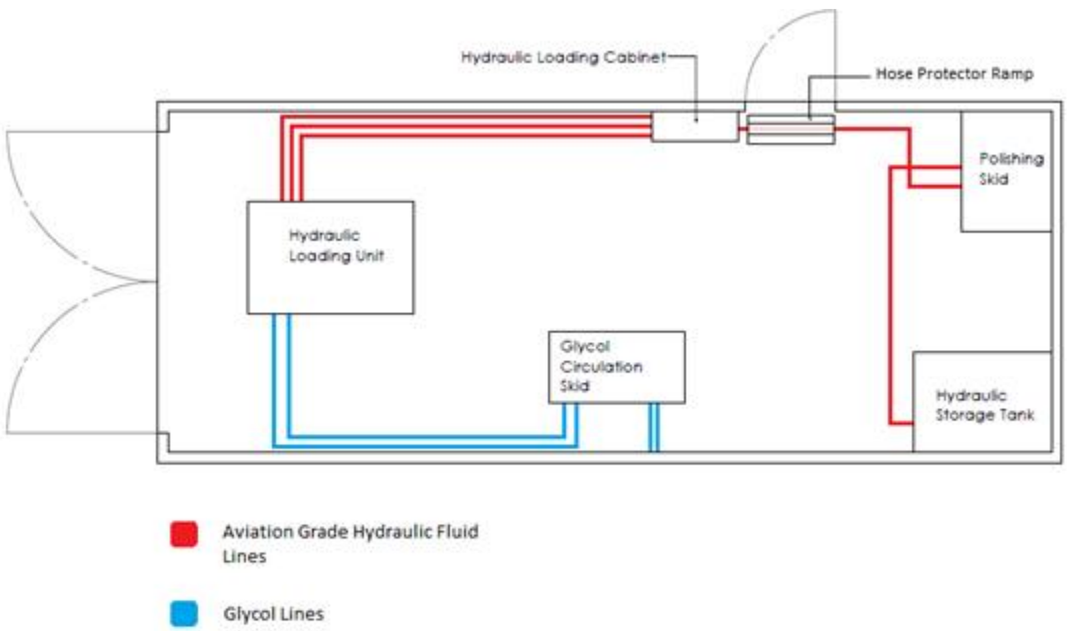


Figure 8: Fluid line diagram

The plan in Figure 8 features all the hydraulic fluid hoses running along the same wall as the loading cabinet while the glycol hoses run along the opposite wall. The cabinet in this design was oriented such that the hose connection ports may face the HLU and allow for less tortuous hose routing paths. Figure 9 displays the annotated three-dimensional model of the proposed hose management system.

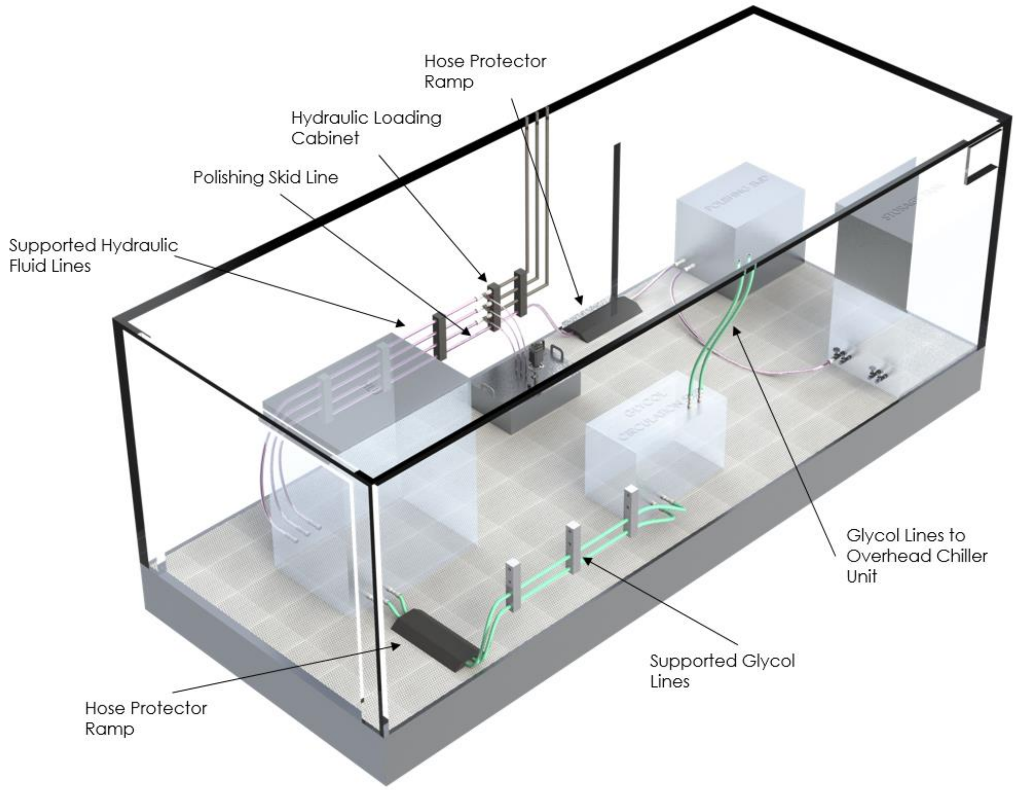


Figure 9: Hose management system features

Some important hose management elements shown in Figure 9 are listed:

- Hose ramp protectors are placed on top of the glycol lines to the HLU and the polishing skid line section in front of the door. These hydraulic fluid resistant, high-density polyethylene ramps reduce tripping hazards and protects hoses [5].
- The hydraulic fluid and glycol lines running to the HLU are supported on the wall to keep hoses organized and prevent walkway cluttering (need 6.3).

This system allows for the HLU to be placed in the room and easily hooked up to the polishing skid or hydraulic loading cabinet and glycol lines as the hoses are already in place (needs 1.1 & 1.3). Hooks could also be placed on the wall next to the HLU such that the hoses may be looped and supported after testing. This would further reduce tripping risks posed by hoses to the operators.

For HLUs, that exceed the allotted room space, ports could be installed in the wall next to the large door. These ports could be pipes with threads on both ends such that hoses could be attached to them from the inside. Extra hoses could then be threaded on to the HLU outside the room and into the port threading. This would allow for easy set-up of turbine testing with large HLU's external to the room. The ports would then be closed with end caps when not in use.

3.1.3. Room Construction

A mobile trailer was selected for the hydraulic loading room design, similar to the current trailer shown in Figure 10, but with different dimensions.

Figure 10: Current hydraulic loading trailer [2]

The trailer will house all of the hydraulic loading components with the spill containment design built under the trailer, replacing the trailer floor. The trailer will be custom construction with two doors, a small door and a large double swinging door. The trailer is to be oriented in the same way as the current hydraulic loading trailer, with the small door located on the South West wall and the large door located on the South East Wall. With custom trailers, any type of insulation for the walls, roof and floor can be specified. The thermal resistance values for wall, floor and ceiling assemblies for this trailer were based on the recommended values from the National Energy Code of Canada for Buildings [7]. The trailer dimensions and thermal resistance values are listed in Table V.

TABLE V: HYDRAULIC LOADING ROOM SPECIFICATIONS

Specification	Value
Dimensions	
Trailer Dimensions (LxWxH)	30 ft x 12 ft x 10 ft
Small door dimensions (H x W x t)	6.7 ft x 3 ft x 1.75 in
Large Door Dimensions (H x W)	9.5 ft x 10 ft * thickness not specified
Thermal Resistance Values [hr-ft^2-°F/Btu]	
Wall	20
Roof	20
Floor	7.5
Doors	5

The trailer is constructed with the ability to be moved via crane. The dimensions and orientations of the doors are shown in Figure 11.

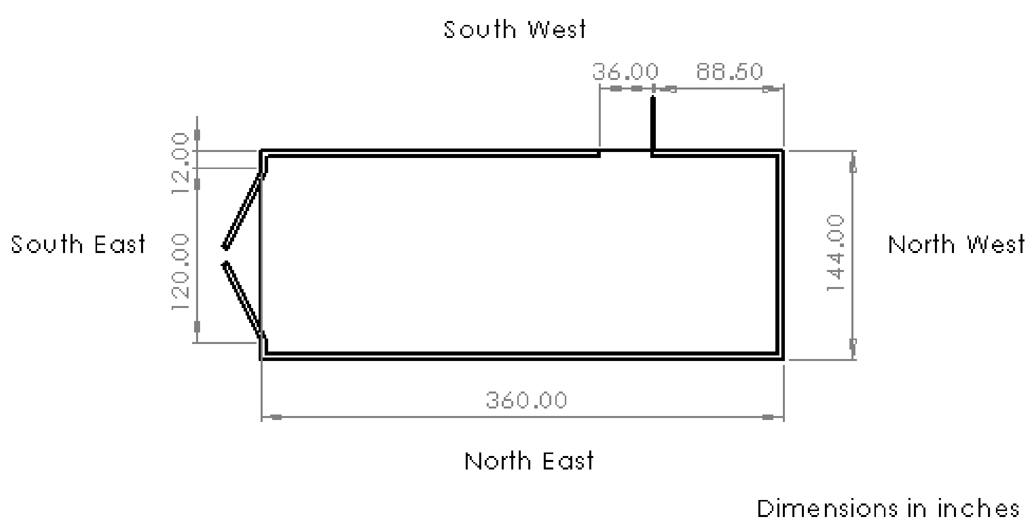


Figure 11: Dimensions and facing direction of trailer

All of the specifications of the trailer were intended to be reiterated to the trailer manufacturer to be constructed as was designed.

3.2. Ventilation

The ventilation system has been broken down into two sub-systems due to the nature of the design. A separate analysis is required for both the system responsible for providing clean air and removing the polluted air. As such, the main ventilation and local exhaust systems will be presented in separate sections of this report.

3.2.1. Local Exhaust Ventilation

Local exhaust systems are designed to prevent process emissions from entering the workplace by capturing pollutants in the local vicinity of the source [8]. Local exhaust systems generally contain the following basic elements: [9]

- Exhaust hood to capture process emissions
- Ducted system to transport captured pollutants away from the workspace
- Air cleaning device, such as an air filter, to remove airborne contaminants from the air
- Air moving devices, such as a fan, to create the motive power to transport captured air
- Exhaust stack to discharge air into the atmosphere

A local exhaust system is required in the hydraulic loading room to capture toxic fumes and gases from hydraulic oil spills throughout the room. Each of the above elements are required for a successful design and have been examined further in the following sections. It should be noted that an air cleaning device is optional since pollutants are exhausted outside.

3.2.2. Local Exhaust Duct Design

Taking these principles into consideration, the design team determined that the spills within the hydraulic loading trailer should be controlled to drain directly in front of the local exhaust hood. Our design incorporates a side draft hood underneath the perforated flooring positioned in front of the immediate fluid retention area, with a capture range of 6 inches. Since each exhaust hood requires an air flow rate of 250 cfm, three side draft hoods have been placed along this wall, to properly exhaust contaminants from the workspace (need 5.2).

Round ducts have been chosen for this design because this geometry (1) offers uniform velocity to resist contaminants from settling, (2) can withstand higher static pressures which are common in industrial ventilation exhaust systems, and (3) is easier to seal compared to rectangular ducts.

Each straight length of duct, elbow, and hood entry losses were considered in the design of the local exhaust system. The total pressure drop that the fan must overcome is 0.452”wg at standard conditions, and the duct material was chosen to be aluminum due to its compatibility with Skydrol LD-4.

3.2.3. Local Exhaust Fan Selection

Fan selection was based on the required air flow rate for the exhaust system as well as the associated pressure drop throughout each of the ducts. To achieve the required transport velocities and overcome the pressure drops throughout the exhaust system as specified in Appendix A Section 2.2.4, a 750 cfm, backward-curved, centrifugal fan with 10-inch blades was required for this application.

3.2.4. Local Exhaust Stack

An exhaust stack should be incorporated into the final duct system design to protect people walking outside the room from inhaling toxic contaminants. An exhaust stack height of 12 feet was selected, recommended from ASHRAE standard 62.1 [10]. A weather cap has been included in our duct design such that foreign objects cannot be introduced into the system such as birds or other wildlife.

3.2.5. Ventilation Air Supply System

The final design selected for the supply side of the ventilation system consists of a fan, three diffusers, a series of ducts, a fresh air intake vent, as well as an integrated heater core. An overview of the air supply system is shown in Figure 12.

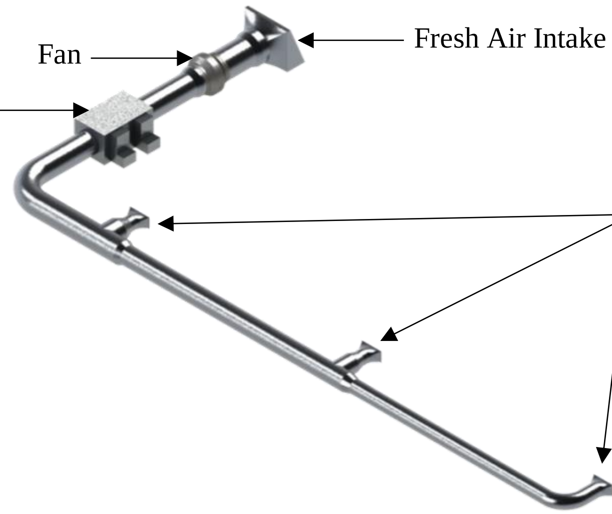


Figure 12: Ventilation air supply system

Figure 12 provides a visualization of the pieces referred to in Table VI. The ventilation system must be able to provide a total airflow of 750 cfm and provide this air efficiently to all areas of the room. The following sections discuss the ventilation system in detail, focusing on the ductwork, diffusers, fresh air intake and fan requirements.

3.2.6. Air Supply Ducts and Duct Sizing

Ducts were selected based on the desired velocity range for each flow rate to try to balance the pressure losses as well as to reduce space claim. This resulted in ductwork varying in diameter from six inches to twelve inches in diameter. Table VI summarizes the velocity and in the ductwork for adequate fan selection. Appendix A provides further details for these calculations.

TABLE VI: AIR DUCT SUMMARY

Location	Diameter of Duct, in	Cross-Sectional Area, ft^2	Flow Rate of Air, cfm	Velocity of flow, ft/min
Air Intake	20 x 18 (L x W)	1.875	750	400
Air Intake to fan	12	0.7854	750	955
Fan to Heater	10	0.5454	750	1375
Heater to Tee 1	10	0.5454	750	1375
Tee 1 to Tee 2	8	0.3491	500	1432
Tee 2 to Diffuser 3	6	0.1963	250	1273
Diffuser Exit	10 x 6 (L x W)	0.34	250	735

Generally, for smaller ventilation systems, in-duct velocities are recommended to be below 1200 ft/min to keep noise levels and pressure losses relatively low [11], with maximum velocities limited to 2400 ft/min. Although the velocities through the ducts are up to 20% higher than the recommended value of 1200 ft/min, noise is not a major concern, and the team would rather specify slightly higher velocities than specify larger ducts due to space constraints in the hydraulic loading room, particularly in the vicinity of the hydraulic loading cabinet where the tubes carrying hydraulic fluid to and from the test engine are located. To eliminate corrosion of the exposed ductwork with hydraulic fluid, the team recommends an aluminum alloy duct instead of the commonly used galvanized steel.

3.2.7. Diffusers and Air Circulation Patterns

In order for the air ejected from the diffuser to reach the other side of the room, a throw of at least ten feet must be attained. Additionally, the 22.5° spread of the diffuser should provide enough throw to cast the air to the side of the trailer and provide a well distributed, non-intersecting spread. To accomplish this task, the diffusers were evenly spaced along the length of the trailer, resulting in a spacing of ten feet between diffusers and five feet from the trailer ends. The high sidewall diffuser was placed near the wall of the room and blows air towards the opposing wall, such that the air travels across the room to the other side. The spread of high sidewall diffusers is often field adjustable between 0°, 22.5°, and 45°.

A ten inch by six inch high sidewall diffuser was selected for this application. From an airflow perspective, the air is to be ejected from the diffusers, travelling along the ceiling of the trailer (above conditioned space) and then drawn downwards, across the room, and through the subfloor where the air exits the space. Figure 13 shows the expected flow of air through the room.

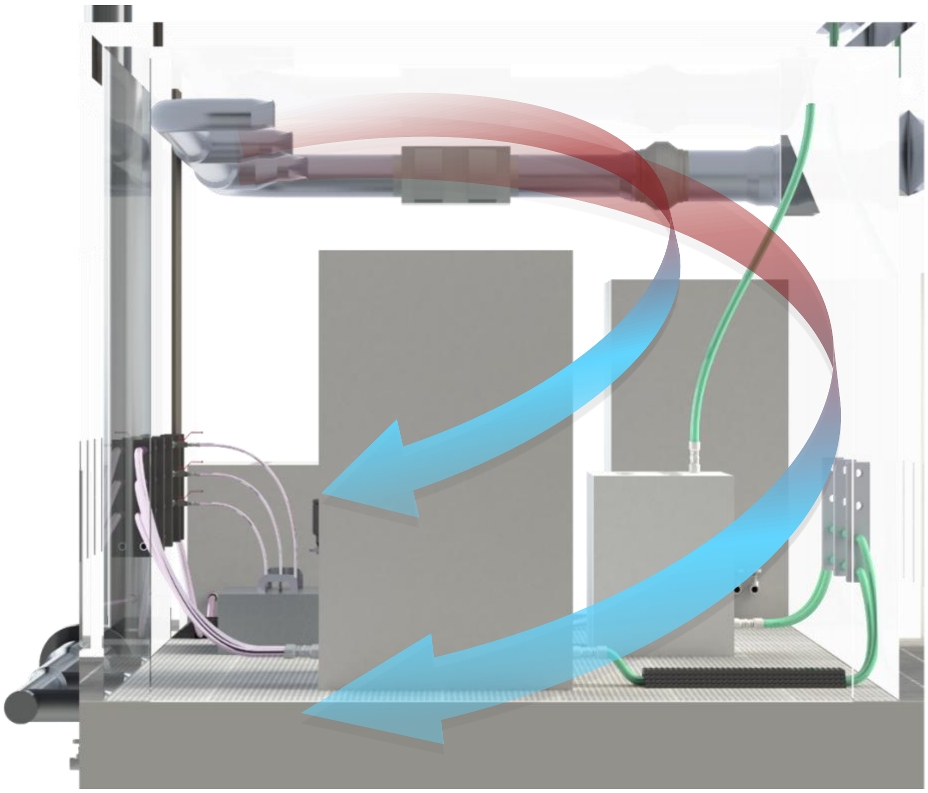


Figure 13: Air circulation patterns

Figure 13 shows the expected airflow patterns through the hydraulic loading room. Air exits the diffusers along the top left corner of the room (from view depicted in Figure 13) and is thrown to the opposing wall. The remaining energy of the air is dissipated as the air travels downwards along the wall and is pulled towards the air intake hoods located in the sub-floor. This should promote mixing of the air as well as pull the air towards the local exhaust hoods to draw air over the regions where employees will be working.

3.2.8. Fresh Air Intake

The fresh air intake is located above the fluid storage tank. This location was chosen as the front of the trailer has ample space to mount both the heater core and the fan, and the extension of the duct toward the west wall of the trailer provides a clean and accessible layout of the ductwork. The intake is mounted on the outside wall of the building, on the opposite side of the building to where the exhaust stack is located. The fresh air intake is also mounted near the roof of the building and thus should not fill with snow and debris. A coarse wire mesh screen is required to prevent objects and animals equivalent to 0.5 inch in diameter or larger from entering the air supply system [10].

The team also considered filtering the supply air to reduce the amount of dust and debris passing through important components of the HVAC system such as the fan and heating coils. Noting that the primary operation of this building occurs in the winter, the main concern is with drawing in large amounts of snow. To reduce the risk of snow ingestion, the area of the intake has been increased to limit the inlet velocity of the air to 400 ft/min, due to the recommended range of 350 to 400 ft/min [12] [13]. This corresponds to a total face area of 2.5 square feet for a flow rate of 750 cfm and a wire mesh providing an open area of 75%, which is obtained by using a readily available 2 x 2 mesh size (two openings per inch in both directions) with a 0.063-inch wire diameter.

3.2.9. Fan Selection for Air Supply System

An inline duct blower was selected as the fan of choice for the supply side of the ventilation system. Placing the fan in line with the duct system eliminated a direction change as well as the difficulty of placing the fan in a good location relative to the air inlet as would be the case with a typical squirrel-cage (centrifugal) fan. The VTX1200L inline duct blower from Vortex Powerfans was determined to be a good fit for this application, providing 0.5 in. wg of static head at an airflow of 761 cfm [14].

The ventilation system complies with client need 5, 5.2, and 5.3 which state that the ventilation system must be able to provide adequate ventilation such that harmful contaminants are evacuated from the air and maintains a suitable air quality for people to work in. The full list of needs is provided in Section 1.2.

3.3. Heating System

This heating system is comprised of a Thermon model DIF insert duct heating element and the ductwork that it is packaged in. The heating system has the capacity to supply 26 kW (88200 Btu/hr) of heat to the space, based on heating outdoor air at -37 ˚C (-35˚F) to an indoor temperature of 5˚C (41˚F). Refer to Appendix A, Section 3.1 for the heating calculations. A CAD render of the heating elements installed into the ductwork is shown in Figure 14. The heating elements are a simplified model to visualize the size and positioning.

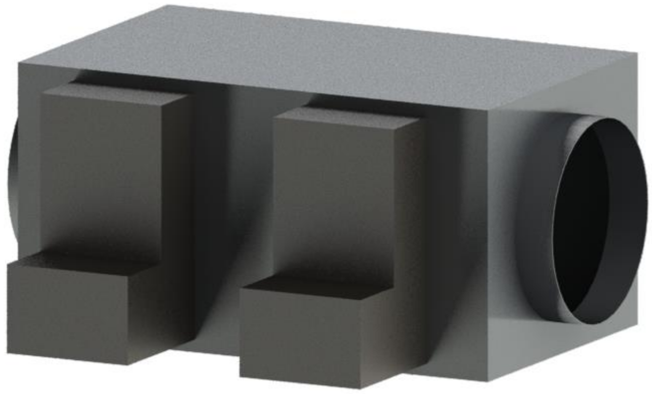


Figure 14: Simple model of in-duct heating system

The following sub-sections describe the heating element specifications and the size and materials that are required for the ductwork.

3.3.1. In-Duct Heating element

The selected in-duct heating element is an insert duct heater with finned tubular elements from Thermon model DIF [4]. This type of heating system is simple to remove for repairs or maintenance if required, are thermostat controlled and fully enclosed to prevent hydraulic fluid from settling on the heating element, which satisfies the needs 1.4, 4.2 and 4.1 specified in Table II.

The first iteration of this design was to have one heating coil with a heating capacity of 27 kW (92,127 Btu/hr), however the resulting velocity passing through the duct was lower than the required minimum velocity to pass over the heating coil. Therefore, to achieve the required 26 kW of heat capacity, two 13 kW elements were analysed. The 13 kW heating elements are smaller than the 27 kW one, thus the duct could be smaller, achieving a higher velocity through the duct. These heating coils are safe to install in tandem as long as the inlet temperature of either coil remains below 77˚F (25˚C) [4]. The temperature leaving the first heating element and entering the second element is 10˚F (-12˚C), which satisfies the inlet temperature requirement. The 13-kW heating element with its dimensions is shown in Figure 15.

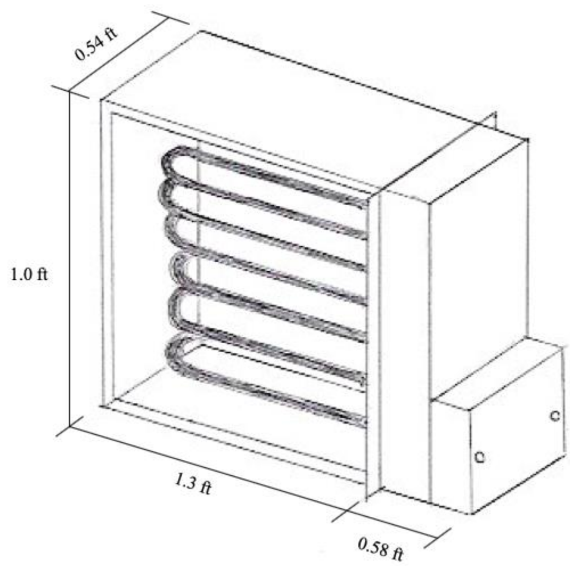


Figure 15: Dimensions of insert duct heater, redrawn from [4]

The minimum velocity that must pass through the heating element was 500 ft/min [4]. The velocity passing through the ductwork, shown in the next section, was calculated as 505 ft/min, thus the minimum velocity requirement was satisfied.

3.3.2. Heating Ductwork

With the dimensions of the heating element shown in Figure 15, a custom duct size was selected just large enough to fit the heating element to maximize the velocity passing through the duct. The ductwork dimensions are shown in Figure 16.

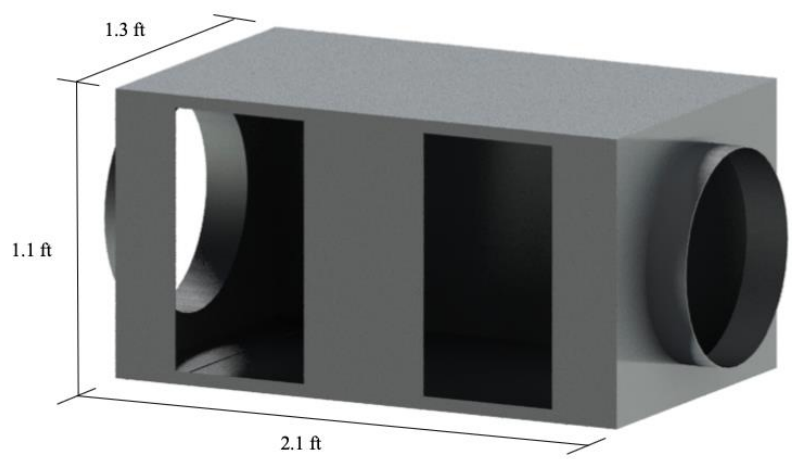


Figure 16: Duct dimensions for insert heating element

The heating duct is comprised of a rectangular centre section with two rectangular-to-round duct transitions at the ends to connect to the ventilation ducts. The ductwork is constructed from Aluminum sheet metal and can be found from any custom ductwork supplier. Aluminum is compatible with Skydrol LD-4 hydraulic fluid, which satisfies need 7.1 in Table II.

3.4. Spill Prevention

Our team developed a spill collection strategy to reduce the number of likely spills within the hydraulic loading room which will ideally eliminate several hours of cleaning required of MDS personnel each time that a test is completed. Much of the spill prevention system has been designed in accordance with available hydraulic fittings and components from Parker. A brief description of each component will be provided in the following sections to illustrate the functionality of the auxiliary bleed line concept that our team decided to pursue.

3.4.1. Connection Style Considerations

The ORFS and JIC connection styles are most commonly used in industry and have both been considered for the auxiliary bleed line concept. The exact connection style that is used will depend on the hose connection styles that are currently in place as well as OEM preferences. Figure 17 shows the aforementioned connection styles that could be used for the auxiliary bleed-line concept. Since the current connection styles were considered outside of the project scope, the team decided to complete the conceptual design of the system using a JIC connection style. It should also be noted that JIC fittings are used heavily in the aerospace industry in the production of commercial airliners, which aided our justification of choice [15]. An ORB connection style is still required for some of the connections within this system. Lastly, all hydraulic fittings and adapters have been selected to have a stainless-steel body to account for the material compatibility with Skydrol LD-4 and to be rated for high pressures, to meet client need 3.1.

Figure 17: JIC and ORFS connection style comparison [15]

3.4.2. Diagnostic Port

Parker offers a line of specialty-type adapters, specifically designed for diagnostic, fixed-flow control, and bleeding applications. At the heart of this product line is the in-line diagnostic tee, as illustrated in Figure 18. The diagnostic tee, supplied by Parker, is available in 16 different configurations including both an ORFS and 37° flare JIC connection style [16]. A SAE -4 (7/16-20 UNF) diagnostic tee comes standard with most diagnostic ports and runs perpendicular to the main fluid stream. The diagnostic tee used in our design has a -16 JIC male to JIC swivel-female connection and is rated for 9500 psi static pressures and 6000 psi dynamic pressures. This component will be installed at the hydraulic loading cabinet in between the rubber and steel lines.

Figure 18: Diagnostic tee [16]

The in-line diagnostic tee has been designed to work in conjunction with Parker's fluid sampling and fluid pressure and temperature measuring diagnostic equipment. Although outside the scope of this project, fluid sampling and fluid measurement equipment could benefit the client and OEM companies by providing a means of fluid health monitoring.

An adapter must be installed at the diagnostic port on the diagnostic tee for fixed-flow control applications. This hydraulic component will be used as an intermediate connection between the diagnostic tee and the hydraulic hoses running in parallel with the mainstream of hydraulic fluid traveling to and from the client's test stand. The adapter used is a -6 37° flare JIC to -4 ORB fitting [17].

3.4.3. Hydraulic Valve

A hydraulic on/off valve is required for the system design so that the flow of hydraulic fluid through the diagnostic port can be controlled. While the test stand is in use, this valve is to remain in the off-position and should only be turned on when the engine tests have been completed and the HLU is to be removed from the hydraulic loading room. A -6 6000 psi JIC ball valve [18] has been selected for this feature of the design and is shown in Figure 19.

Figure 19: Hydraulic ball valve [18]

3.4.4. Hydraulic Hoses

All hydraulic hoses used for this system design should be compliant with Standard AS620 and should be compatible with Skydrol LD-4. Hoses should also be created with the proper JIC hose-ends to match the JIC hydraulic fittings used in this design.

Hydraulic nipples are required in this design for connecting auxiliary equipment to hydraulic hoses. JIC 6-6 nipples have been used to connect hydraulic lines to the shut-off valves but an ORB to JIC 6-6 nipple is recommended for connecting hoses to the secondary hydraulic storage tank.

3.4.5. Tank Breather

The purpose of the hydraulic tank breather is to allow an air flow into and out of the secondary hydraulic storage tank. When filling the tank, hydraulic oil that enters will pressurize the air in the tank and could affect the flow of fluid or cause the tank to fail. Similarly, when pumping fluid out of the tank, hydraulic oil that leaves the system will create a vacuum pressure and could cause negative effects. A breather element will allow a clean supply of air into the tank to prevent over-pressurization and vacuum pressures.

3.4.6. Secondary Storage Tank

The secondary storage tank is primarily used as an intermediate holding tank. One of the main benefits to an additional storage tank is that this feature can contain hydraulic fluid without being exposed to the environment. This essentially reduces the chance of contaminants such as snow, dirt, and water from entering the contained fluid and allows for the hydraulic oil to be re-processed, thus meeting client's needs 2.2 and 2.3. Additionally, the implementation of a breather unit filters and prevents hydraulic fluid off-gases from entering the workspace, thus meeting client need 5.3. A model of a possible secondary storage tank has been presented in Figure 20. The conceptual storage tank features a low-profile design and a capacity of 200 Liters made from 6061 aluminum. These features enable a gravity driven flow into the tank and enough reservoir space to empty the pressure, suction, and case drain lines.

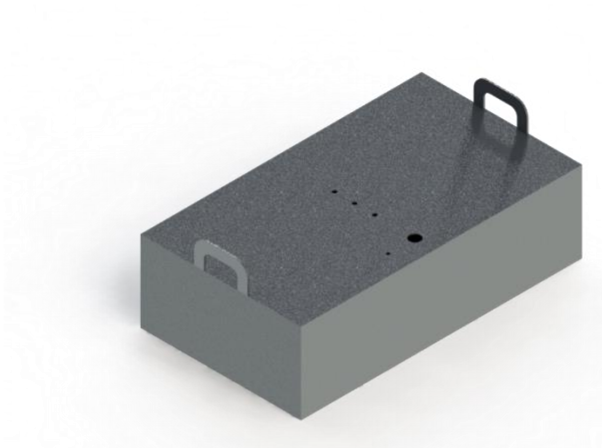


Figure 20: Secondary storage tank

3.4.7. Hydraulic Pump

A hydraulic pump is used in this system for transporting hydraulic fluid from the secondary storage tank to the primary storage tank. Our group considered both manual and electric pumps that were designed to extract fluid from barrels, as the secondary storage tank essentially has the same volume as a standard barrel of oil. Since the electric pump requires less work to operate and can move fluid much quicker, the electric hydraulic pump was chosen for this feature of the system. This style of hydraulic pump is readily available from LUTZ and features a capacity of 6 gpm and a delivery head of 21.3 feet [19]. An electric pump has been presented in Figure 21 but alternative pumps with similar specs could be used in place of this one.

Figure 21: Electric hydraulic pump [19]

One of the main issues the client was experiencing was that every time a hydraulic line was cracked, fluid would be at risk of being contaminated. The hydraulic pump is the final piece of the puzzle which allows fluid in the pressure, suction, and case drain lines to be emptied without having to disconnect the hydraulic lines. This feature helps our system to meet client need 3.2.

3.4.8. Hydraulic Seal Material

Hydraulic O-ring and seal material must be considered when designing hydraulic systems containing Skydrol LD-4. Most ORFS and ORB fittings come standard with nitrile 90-durometer O-rings, which is extremely incompatible with Skydrol LD-4. If these connection types are used, it is recommended that the seals get replaced with ethylene-propylene rubber (EPM, EPR, or

EPDM) or Teflon O-rings. Both materials are highly compatible with Skydrol LD-4, have temperature ranges from -62℃ to 121℃, and are available from Parker [20].

3.4.9. Final Design Performance

The rate at which hydraulic oil is directed through the ball valve will be dependent on the static elevation head of fluid sitting in each hydraulic line. However, it would take approximately 3 minutes for this conceptual design to drain a single column of fluid (~75 Liters) sitting in one of the steel lines at the existing hydraulic loading cabinet. This concept dramatically reduces the time for draining hydraulic fluid, which currently is estimated to take upwards of an hour. Figure 22 shows how each of the components are integrated into the final spill prevention system design.

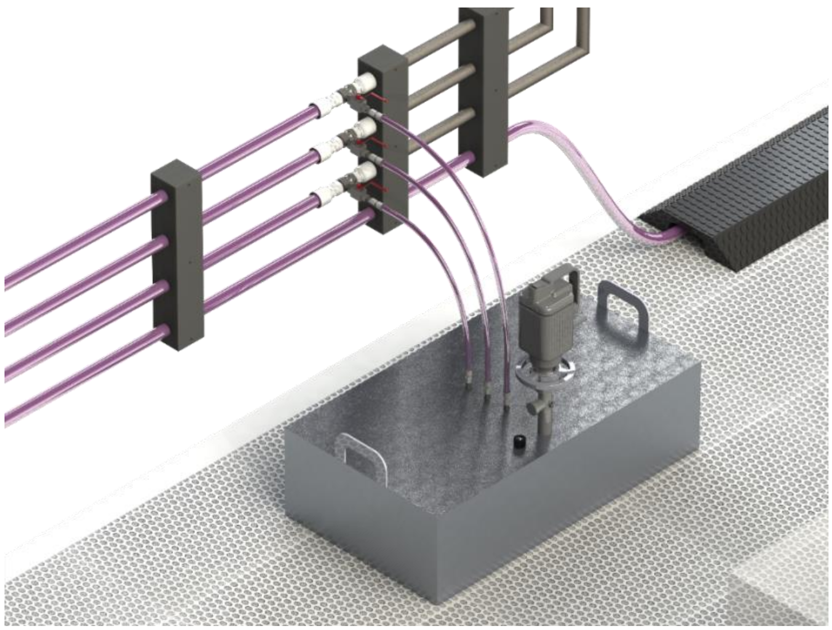


Figure 22: Auxiliary bleed line conceptual photo

As seen in Figure 22, the in-line diagnostic tee is installed between the steel and rubber hoses alongside the wall of the hydraulic loading room. A diagnostic port is installed on the diagnostic tee which attaches to a hydraulic ball valve. The ball valve controls the flow of fluid through a hydraulic line which attaches to the secondary storage tank, using JIC nipples at either end. Figure 22 shows that this configuration of hydraulic components can be used for all three lines at the hydraulic loading cabinet. In addition, the breather unit and electric hydraulic pump have been modelled on top of the secondary storage tank to show a possible location for these elements.

After a test has been completed, workers would ensure that the HLU is not running before opening the ball valves to the position that is shown in Figure 22. After hydraulic fluid has been drained in the secondary storage tank, workers could pump the retained fluid into the primary storage tank where it would be recycled through the polishing skid for the next set of tests. The auxiliary bleed line concept meets all the client's needs pertaining to spill prevention and is therefore considered to be a successful design.

3.4.10. Glycol Spill Prevention

Although the focus of this system design has been on preventing hydraulic spills within the hydraulic loading room, the design team felt that it was necessary to consider spill prevention tactics for the glycol hoses as well. Both concepts discussed in Section 2.3 of this report pertain to glycol hoses as well. Although the auxiliary bleed line concept was selected for development, the quick-connect couplers would work for the case of glycol hoses as there are no restrictions to the flow or pressure within the glycol circulation loop. The addition of quick connect couplers to the glycol circulation system eliminates the need of the barrel used for holding glycol hoses once a test has been completed. Thus, this concept would reduce the amount of glycol spills in the hydraulic loading room and eliminate any open-faced storage tanks.

3.5. Spill Containment

This section serves to investigate the design of a perforated floor spill containment system carried forward from Section 2.4. This analysis is conducted by initially establishing likely spill areas to determine the required coverage of the perforated floor. The determined coverage required is then used to design a conceptual sub floor reservoir and collection system for the hydraulic loading room.

3.5.1. Spill Likelihood Analysis

A perforated floor grate system for the hydraulic loading room would be comprised of a latticework of grates suspended over a storage basin. The storage basin would incorporate sloped surfaces in order to funnel the incoming fluid spills into a collection area (need 6.1). The perforated grate system could be used in only key sections of the hydraulic loading room where spills were probable, so an identification of high spill likelihood areas was conducted. The results of this assessment are shown in Table VII.

TABLE VII: SPILL LOCATION PROBABILITY SUMMARY

Spill Probability	Location	Reasoning
High	Hydraulic loading unit aviation fluid hose attachment points	After testing these lines are disconnected from the HLU and some leftover fluid in the lines may leak onto the floor.
	Hydraulic loading unit glycol hose attachment points	After testing these lines are disconnected from the HLU and some leftover fluid in the lines may leak onto the floor.
	Hydraulic Loading Cabinet	Draining of the lines to the engine post testing could results in spills outside of the catch basin. Emptying this basin also carries a possibility of spilling onto the floor
Moderate	Glycol circulation skid hose attachment points	These hoses are infrequently detached however doing so would pose a spill risk.
	Fluid Polishing skid aviation fluid hose attachment points	The polishing skid is often used pre-testing and hose disconnections could cause spilling onto the floor.
	Fluid storage tank aviation fluid hose attachment point	Aviation fluid attachment point causes possibility of leak or spilling during disconnections.
Low	All hose sections	Small possibility of hose ruptures or leaks during testing.
	Glycol circulation skid hose attachment points to the overhead cooling unit	These attachment points are very infrequently detached and thus pose minimal spill risk above possible leaks.

Based on the spill location likelihood assessment in Table VII, spill collection for high and moderate probability spill locations would require coverage underneath the hydraulic loading cabinet and the hose attachment points for the hydraulic loading unit, polishing skid and glycol circulation skid. From this analysis and fluid line and equipment diagram in Figure 8, we can infer that coverage of the moderate and high probability spill areas would require perforated flooring with coverage extending over most of the room. For construction simplicity, the perforated floor system was designed to cover the entire hydraulic loading room floor area.

3.5.2. Perforated Floor Conceptual Design

Need 2.2, outlined in Table III, asserts that spills of aviation hydraulic fluid and glycol should be ideally be kept separate to allow for the possibility of recycling. This poses a challenge however, as consultations with the client revealed attachment point locations for the fluid lines to the hydraulic loading unit as well as the unit dimensions can vary greatly between units. Since these attachment points are considered high spill probability areas, creation of a system with two different collection locations and subfloor gradients that would accommodate all HLU types is unlikely. Furthermore, separation of spills with two distinct subfloor gradient collection systems would prove futile as debris contaminants from operator boots in winter conditions would likely eliminate the possibility of fluid recycling. This means that the perforated floor design will utilize only one fluid collection fluid area which would contain any fluid spills and debris.

With the general guidelines for the spill collection system established, a conceptual design was modeled for a single basin system. Simplicity was emphasized in the approach for the subfloor gradient design. Our team deemed the simplest method to be one in which three sloped sections met at a location along the wall that would serve as a collection basin. The annotated depiction of this system is displayed in Figure 23. The wall resting at 90 degrees relative to the ground, where the three slopes meet, hosts three ports for the ventilation system. These exhaust ports are placed above the collection basin in order to evacuate harmful vapors emitted by aviation grade hydraulic fluid. Further details of this exhaust system are discussed in section 2.1.

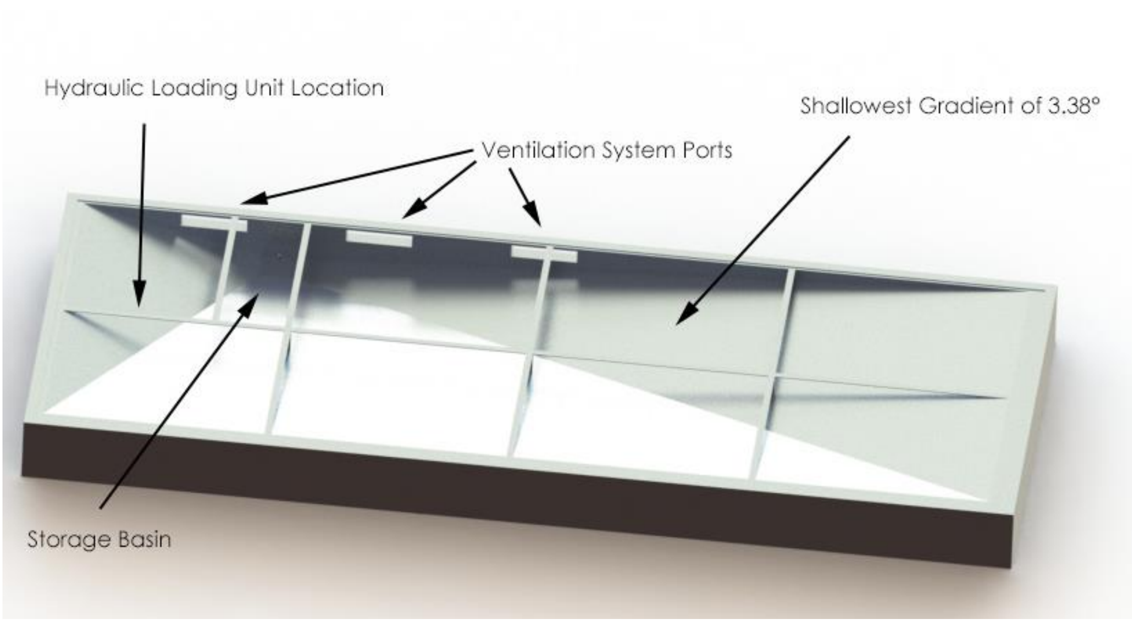


Figure 23: Fluid collection system

The cross members shown in Figure 23 are used to support the perforated grate section panels that lie above the collection system. The smallest support section corresponding to the smallest perforated floor panel is located over the basin. This is done in order to allow easy access for debris removal to the mesh that protects the drainage pipe. The small panel is also located where it can be easily opened post hydraulic loading unit removal. The perforated floor grates should be selected with a raised pattern to decrease slip likelihood (need 6.2). The storage basin depicted in the Figure 23 can hold approximately 1100 Liters of fluid before leakage into the vents occurs. In practice however, the system should be drained prior to this level of fluid collection. Emptying of the basin would occur using a handpump connected to an external valve to draw the fluid into barrels for disposal. The location of this exit channel is seen in Figure 24.

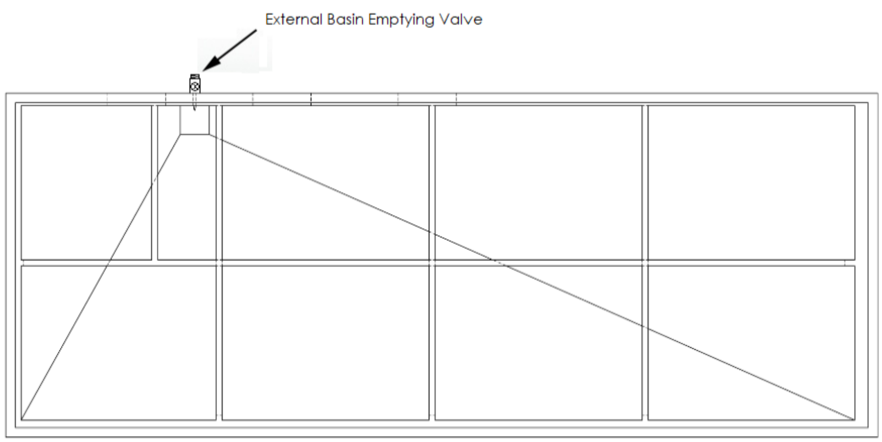


Figure 24: Spill collection system top view

The height of the subfloor system had to be chosen in a manner that allowed for the external valve to be high enough to attach a pump hose easily and not interact adversely with the concrete pad surrounding the room. For this dimension, a height of 8 inches was chosen for the centerline height of the exit channel. To keep the overall room height reasonable, a total subfloor height of 24 inches was chosen. This height meant that the shallowest gradient in the room, depicted in Figure 23, would be 3.38 degrees from the horizontal. A slope of over 3 degrees seemed reasonable to funnel spilt glycol or hydraulic fluid into the basin. Figure 25 and Figure 26 depict the front and side views of the subfloor fluid collection system respectively.

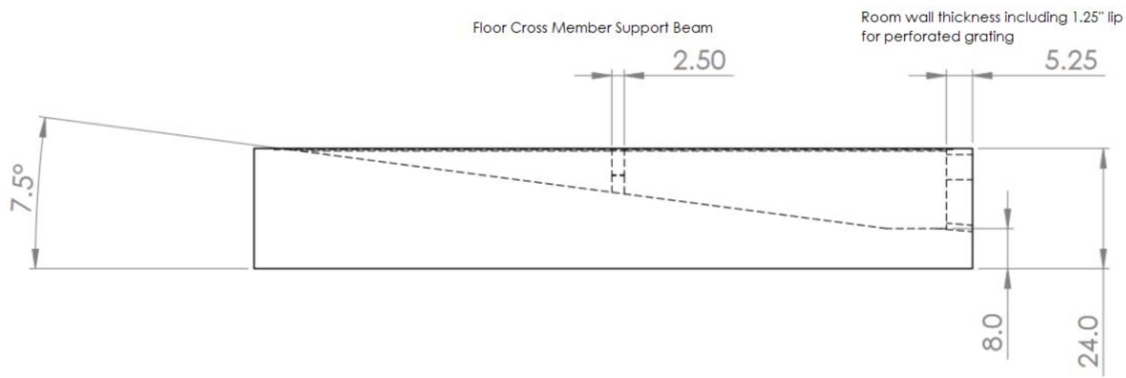


Figure 25: Spill collection system front view

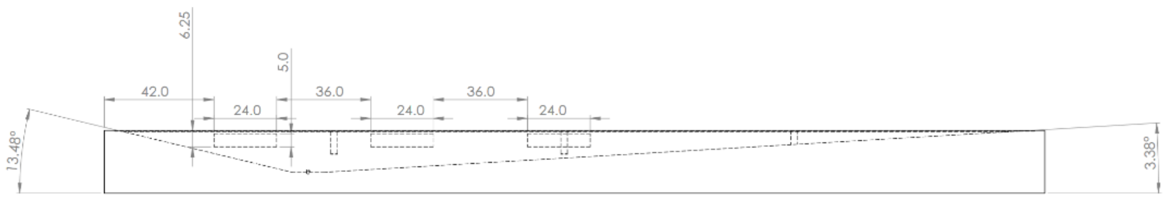


Figure 26: Spill collection system side view.

3.5.3. Spill Collection System Material Considerations

The fluid collection system must be able to withstand interactions with water, glycol and aviation grade hydraulic fluid. Common construction materials for floor gradients include galvanized steel, stainless steel and aluminium. Galvanized steel may pose a problem in this application as zinc does not maintain a good compatibility rating with the aviation fluid Skydol LD-4 [5]. Stainless steel or aluminum both have excellent compatibility with aviation hydraulic fluid however the former is relatively more costly. A floor gradient system made of aluminium would be lighter weight than stainless steel and less costly at the expense of requiring special welding techniques [21].

4. Schedule Management

This section of the report presents an updated version of the Gantt chart, shown Appendix C. The team did not follow the schedule as successfully in this phase of the project as the previous phases. Design of the ventilation system proved to be more complex than anticipated and every other design was dependent in some way on the ventilation system design. This complexity pushed the design optimization and finalizing task into the allotted time for developing the report. This variance in the schedule was corrected by consulting a professor who teaches HVAC on November 3, 2019 and getting the final design completed. This deviance in schedule was not too severe and the final deliverables to the client will be able to be completed before the deadline.

5. Conclusion

MDS AeroTest occasionally requires the use of a hydraulic loading room, which houses equipment necessary for the simulation of hydraulic loads on Rolls Royce and Pratt and Whitney gas turbine engines. Our client has requested an overhaul of their current hydraulic loading room to improve the general layout of the equipment in the room, improve the current system used for collecting spills, and create a safe working environment for MDS AeroTest personnel. As a solution to the many challenges that MDS AeroTest faced, our team developed an improved layout plan, ventilation system, heating system, spill prevention system, as well as a spill containment system to target the customer's needs.

To meet all the requirements set out by MDS AeroTest, our team collected the needs, target specifications, and constraints for the project based on client consultation and research. With this information, our team followed an extensive concept development procedure to devise a solution for each given system that exemplified qualities that would resolve each issue that our client was facing. Concept screening and scoring matrices were used, found in Appendix B, to select an optimal concept based on selection criteria that were weighted in terms of importance. The results of the concept development phase have been summarized in Table IV.

Following the concept development phase, each of the selected designs were investigated further and developed with the aid of the client's direction. Each concept was considered with the client's needs in mind to produce a final design that our client could implement in their test facility. This report has presented conceptual designs, accompanied by figures and drawings to illustrate each system that is to be implemented in the hydraulic loading room. Details of the HVAC system design have been provided in Section 3.3 and Section 3.4 of this report. However, further calculations and analysis are presented in Appendix A. A detailed trade-off study was completed during the concept development phase of the project and has been included in Appendix B.

The room layout strategically places equipment so that hydraulic and glycol hoses are separated neatly along opposing walls and allows the HLU to be installed in the room with ease. The layout incorporates a hose management plan to reduce the amount of hoses crossing the floor and increase the available square footage of the room. In-duct heating elements have been installed in the air-supply system to ensure a comfortable and safe work environment. In addition, local-exhaust hoods have been located beneath the floor to capture any fumes from hydraulic fluid spills. Industrial ventilation systems have been designed to deliver 12 air changes per hour into the hydraulic loading room as required by the Skydrol LD-4 MSDS. Proper ventilation is achieved by controlling hydraulic fluid spills to fall through a perforated floor and gather in front of the local exhaust ventilation system. A hydraulic bleed line has been installed on the hydraulic lines returning from the test stand to capture this hydraulic fluid and eliminate any spills that occur from draining these lines. The bleed line concept will benefit our client by dramatically reducing the time taken to drain the pressure line from approximately 60 minutes to 3 minutes. After much consideration, our team found that this design for the hydraulic loading room would be an optimal upgrade for our client.

6. Recommendations

While designing the individual systems for the hydraulic loading room, our group came across several design improvements that we thought were beneficial for the client but were considered outside the scope of our intended design project. These design recommendations have been provided in Table VIII for the client's convenience.

TABLE VIII: FURTHER DESIGN RECOMMENDATIONS

System	Recommendation
Spill Prevention	Incorporate aviation-grade hydraulic quick couplers into the auxiliary bleed line concept to eliminate the need for threaded connections.
Spill Prevention	Investigate thermoplastic quick couplings for closed-system transfer of fluids that have a low environmental contamination such as glycol.
Spill Prevention	Investigate Parker's line of diagnostic equipment, in conjunction with the diagnostic port, which could be used for in-line pressure and temperature measurements. The diagnostic product line could also be used for in-line oil sampling to evaluate hydraulic contamination caused by problems with filtration or failed internal components.
Hose Management	Installation of hooks on the walls adjacent to the HLU could allow operators to loop and support the hoses post testing. This keeps the room walkway free of hoses between testing operations.

System	Recommendation
Hose Management	Hose adapters could be installed on the wall segments adjacent to the large door. This would allow the internal system to connect to external hoses for oversized HLU tests. Between tests, end caps could be place on these adapters to prevent wildlife incursions.
Heating	Install a space heater if operation of the room without ventilation is required

7. References

[1] Thompson Citizen, "Winter Weather Testing a Competitive Field," 20 March 2019. [Online]. Available: https://www.thompsoncitizen.net/news/thompson/winter-weather-testing-a-competitive-field-1.23669142. [Accessed October 2019].

[2] MDS AeroTest, "Conceptual Design of Hydraulic Loading Room Layout and HVAC," Thompson, MB, 2019.

[3] American Conference of Governmental Industrial Hygienists, Industrial Ventilation: A Manual of Recommended Practice for Design, 28th Ed., Cincinnati, Ohio: ACGIH, 2013.

[4] Thermon, "Air Duct Heaters - DFF, DIF, DFT & DIT," [Online]. Available: https://content.thermon.com/pdf/Caloritech/Catalog/DF_DI_Catalog.pdf. [Accessed November 2019].

[5] Eastman Aviation Solutions, "Skydrol: Specifically Formulated to Meet The Changing Needs of The Aviation Industry," 23 November 2019. [Online]. Available: https://www.eastman.com/Literature_Center/A/AF9.pdf.

[6] King Electric, "King Model KB," [Online]. Available: https://king-electric.com/product/model-kb/. [Accessed November 2019].

[7] Canadian Commission on Building and Fire Codes, National Reseach Council of Canada, "National Energy Code of Canada for Buildings 2017," National Research Council of Canada, Ottawa, 2017.

[8] Committee on Industrial Ventilation, Industrial Ventilation: A Manual of Recommended Practice, 23rd Edition, Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists, Inc. , 1998.

[9] ASHRAE, 2011 ASHRAE HANDBOOK: Heating, Ventilating, and Air Conditioning Applications, Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 2011.

[10] ASHRAE, "ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality," 2019. [Online]. Available: https://ashrae.iwrapper.com/ViewOnline/Standard_62.1-2019. [Accessed November 2019].

[11] F. C. McQuiston, J. D. Parker and J. D. Spitler, Heating, Ventilating and Air Conditioning: Analysis and Design 6th Edition, Hoboken, New Jersey: John Wiley & Sons, Inc., 2005.

[12] V. Asikainen and P. Pasanen, "The Prevention of the Snow Entrance to the HVAC-systems," in *Proceedings of the Clima 2007 WellBeing Indoors*, Helsinki, Finland, 2007.

[13] J. Livingston, "ASHRAE Indoor Air Quality Guide," n.d.. [Online]. Available: https://illinoisashrae.org/images/meeting/040913/iaq_guide.pdf. [Accessed 03 December 2019].

[14] Vortex Powerfans, "VTX1200L," [Online]. Available: http://vortexpowerfans.com/vtx-1200l. [Accessed 28 November 2019].

[15] SSP, "JIC Fittings SAE 37° Flared Fittings," SSP, [Online]. Available: https://www.my-ssp-usa.com/products/fittings/tube-fittings/industrial/flared/jic-fittings. [Accessed 20 November 2019].

[16] Parker, "Diagnostic, Orifice, Bleed Adapters and Specialty Fittings," Parker, [Online]. Available: https://www.parker.com/literature/Literature%20Files/tfd/cat/pdffiles/N-Diagnostic.pdf. [Accessed 15 11 2019].

[17] Parker, "IN-LINE DIAGNOSTIC FITTINGS AND ADAPTERS," Parker, [Online]. Available: https://ph.parker.com/us/en/diagnostic-fittings/16-4-lohl6g5tp-s#CADTab. [Accessed 15 11 2019].

[18] Parker, "Colorflow and Ball Valves," April 2019. [Online]. Available: https://www.parker.com/Literature/Hydraulic%20Valve%20Division/Catalogs/Catalog%20PDFs/Cat%20MSG14-3300%20-%20Colorflow%20and%20Ball%20Valves.pdf. [Accessed 15 11 2019].

[19] Lutz Metex Corporation Limited, "Lutz Drum Pump RE-PP For Complete Drum Drainage," Lutz, [Online]. Available: http://www.metexcorporation.com/Lutz/drum-drainage-RE-PP.htm. [Accessed 15 11 2019].

[20] Parker, "ETHYLENE PROPYLENE 80 DUROMETER O-RING, MIL/AERO (EM163-80)," Parker, [Online]. Available: https://ph.parker.com/ca/en/ethylene-propylene-80-durometer-o-ring-mil-aero-em163-80. [Accessed 15 11 2019].

[21] Metal Supermarkets, "10 Differences Between Aluminium and Stainless Steel," [Online]. Available: https://www.metalsupermarkets.com/10-differences-aluminum-stainless-steel/. [Accessed 25 November 2019].

A. Appendix- HVAC Design Analysis

Table of Contents

List of Figures

List of Tables

1. Introduction

This Appendix presents calculations and analysis that was required for the final HVAC design for the hydraulic loading room. The HVAC design analysis was separated into analysis of supply air ventilation, exhaust ventilation and the heating system.

2. Ventilation

This section provides the calculations and any other relevant information that was required to complete the ventilation analysis. The ventilation system was comprised of both air intake and exhaust ventilation systems and these systems were developed independently. The airflow requirements of the ventilation system is presented first, followed by the development of the local exhaust ventilation system and lastly the air supply or dilution ventilation system.

2.1. Air Flow Requirements

The required airflow for the ventilation rate was determined based on the room size and recommended air changes per hour. The outside dimensions of the trailer are 30 feet long, 12 feet wide and 12 feet tall, including the two-foot tall sloped sub-floor. Noting that the walls are four inches thick and the gradient sub floor cuts out approximately a third of the volume of the sub-floor, the inside dimensions reduce to 29.33 feet long, 11.33 feet wide and 11.17 feet height.

$$Volume = L \times W \times H \qquad (1)$$

$$= 29.33 \times 11.33 \times 11.17$$

$$Volume = 3712\ [ft^3]$$

The material safety data sheets (MSDS) for Skydrol LD-4 aviation grade hydraulic fluid [1] states that good general ventilation should be used to limit the exposure levels to acceptable levels and notes that typically ten air changes per hour is sufficient. The team used the recommended ten air changes per hour to determine the flow rate of air provided to and exhausted from the room.

$$Q = Volume \times ACH \qquad (2)$$

$$Q = (3712\ ft^2) \times \left(10\,\frac{Air\ Changes}{hour}\right)\left(\frac{hour}{60\ minutes}\right)$$

$$Q = 619\ cfm$$

Applying a safety factor of 1.2 to account for losses in the system as well as some uncertainty in the contaminant generation level. Using (2), the new flow rate becomes:

$$Q = 743\ cfm$$

Rounding up to the nearest ten yields,

$$Q = 750\ cfm$$

Thus, the team selected a ventilation rate of 750 cfm as the target air flow for ventilation system design as well as for the heating system.

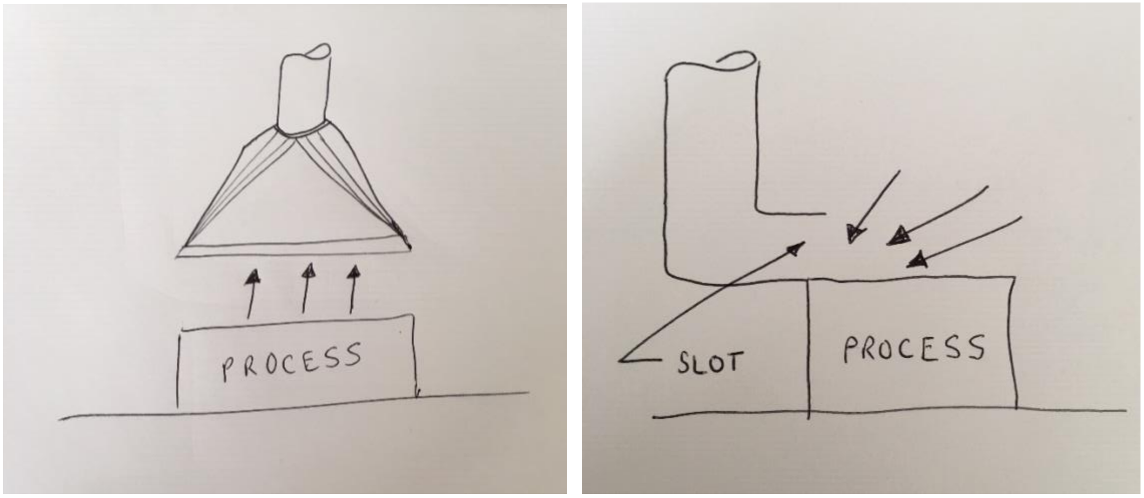
2.2. Exhaust Ventilation Analysis

This section of the report will demonstrate the design process that was taken when considering the various components of the local exhaust system.

2.2.1. Hood Types

The local exhaust hood acts as the point of entry and draws contaminants in by creating an air flow field. A local exhaust hood must be designed to generate an air flow pattern with a sufficient face velocity to control the motion of the contaminant-laden air and air currents associated with the given ventilation system.

Several configurations of local exhaust hoods are available depending on the application of industrial ventilation that is required. Hood types are grouped into two general categories: enclosing and exterior [2]. Enclosing hoods are characterized by their ability to completely or partially enclose the process or source of contamination. This configuration of hood is recommended whenever the process or operation permits. However, due to physical constraints of many industrial processes, a hood may be located adjacent to the emission source, which is described by the latter category, exterior hoods. The enclosing hood and exterior hood have been illustrated in Figure A-1. Where the contaminant is gaseous, and with little velocity, the orientation of the exterior hood is not critical, but an effective exterior hood should be oriented such that thermal buoyancy effects and the air flow patterns within the space are accounted for.



(a) (b)-

Figure A-1: Local exhaust hood types: (a) enclosing hood and (b) exterior hood

It should be noted that the enclosing hood is not a viable option for the hydraulic loading trailer as the exhaust hood and ducting system would need to be located over top of any spills that fall through the perforated flooring. Often, these spills will be located underneath equipment on the floor and would interfere with the placement of additional air ducts. As such, our design will incorporate an exterior hood to capture pollutants from the workspace.

2.2.2. Capture Velocity

The capture velocity can be defined as the air velocity required to entrain airborne contaminants at their source located upstream from the hood. Hydraulic oil spills disperse contaminants into quiet air with a negligible velocity. Due to the condition of dispersed contaminants, a relatively low capture velocity of 50 – 100 fpm is required. For a given exhaust hood, the volumetric flow rate of the captured air can be estimated as follows

$$Q_o = V_o A_o \tag{3}$$

where

Q_o = exhaust volumetric flow rate [cfm]

V_o = capture velocity [fpm]

A_o = hood opening area [ft^2]

Air flow requirements for capturing contaminants at their source will also vary with the distance between the hood and contaminant source. As the contaminant source increases in distance from the hood, a greater capture velocity is required to entrain the pollutant. For this reason, the exhaust hood should be placed nearest to the source as physically possible to maintain adequate air flow in critical areas.

Several hood configurations were considered for this application in order to determine a proper balance between the pressure drop associated with each configuration and the required air flow rate to achieve a capture velocity of 100 fpm. The choice of hood configuration was also dependent on the amount of area coverage for capturing air pollutants. Taking these factors into consideration, a 5”x24” freely suspended, wide-flange hood was selected. The actual air flow rate associated with such a configuration is governed by the following equation:

$$Q_o = 0.75V_o(10X^2 + A_o) \tag{4}$$

where X = the distance between the hood face and the furthest point of contaminant release [ft]. Using six inches as a value for this distance, the air flow rate through the corresponding exhaust hood was determined using (4).

$$Q_o = 0.75(100)(10(0.5)^2 + (0.8333))$$

$$Q_o = 250 \text{ cfm}$$

2.2.3. Hood Design Principles

There are several principles that apply to the local exhaust hood design that have been established from numerous studies and common practice. In order to increase the efficiency of contaminant collection, the following principles should be considered in the design process:

- Hood location should be as close to contamination source as possible.
- The hood opening should be oriented such that contaminants deviate from the natural flow as little as possible.
- The hood opening should be located such that contaminants are drawn away from the occupied zone of the workspace.
- Hoods must be sized so that the volumetric flow rate is equivalent to the flow of air entering the hood face.
- Enclosing hoods must be avoided if there are workers present between the source of contamination and the exhaust hood.

2.2.4. Duct Design

Several design considerations must be made when developing the ducts required to transport the contaminants and air away from the workspace. The main considerations include minimum transport velocity, duct losses, and duct construction.

The minimum transport velocity is defined as the velocity of the air stream which prevents contaminants from settling within the duct system. Minimum transport velocities have been provided as an acceptable range of values categorized by the nature of the contaminant. The values that are listed are usually higher than the theoretical values to account for losses such as duct leakage. Design velocities can be higher than the minimum transport velocity but should never be significantly lower in any portion of the duct system. The minimum transport velocity required for vapors, gasses, and smoke is usually between 1000 and 2000 fpm [2]. The minimum velocity in the duct system design varies between 1200 and 1400 fpm.

Duct losses throughout the whole local exhaust system must be considered and tabulated to determine the total pressure drop in the duct sections before and after the fan location. The duct losses are shown in Table A-I.

TABLE A-I: PRESSURE LOSS SUMMARY

Location	Diameter of Duct, in	Volume of Air, cfm	Velocity of flow, ft/min	Pressure Loss, $\frac{in.wg}{100\ ft}$	Duct Length, ft	Pressure Loss, in. wg
Exhaust Stack	10	750	1375	0.30	12	0.236
Hood 3 to Fan	10	750	1375	0.30	2	0.006
Hood 2 to Hood 3	8	500	1432	0.40	5	0.020
Hood 1 to Hood 2	6	250	1273	0.45	5	0.023
Hood Extensions	6	250	1273	0.45	3 x 0.50	0.007
Tee - Branch	10	250	458	0.035	33	0.012
Tee – Branch	8	250	716	0.12	27	0.032
Tee – Branch	6	250	1273	0.45	20	0.090
Tee - Through	10	500	917	0.15	7	0.011
Tee – Through	8	250	716	0.11	5	0.006

Location	Diameter of Duct, in	Volume of Air, cfm	Velocity of flow, ft/min	Pressure Loss, $\frac{in.wg}{100\ ft}$	Duct Length, ft	Pressure Loss, in. wg
Expander	8-10	500	1132	N/A	N/A	0.003
Expander (x 2)	6-8	250	935	N/A	N/A	0.004
Expander	6-10	250	716	N/A	N/A	0.002
Total	-	-	-	-	-	**0.452**

Each duct moving air from the exhaust hood to the downstream fan have been designed to have similar pressure drops. Since fluid travels through the path of least resistance, the pressure drop across each path should be equal. This approach allows for an even flow of air through each of the exhaust ducts, which translates to a uniform distribution of air. This idea can be achieved either by balancing the pressure drop in each duct by carefully selecting the duct sizes and orifices or using dampers, which are adjustable obstructions in a duct used to control the flow of air through a series of ducts.

The HVAC ducts should be composed of a material that is compatible with Skydrol LD-4 and allows for a smooth transition of air between different segments of the duct system. While it is common for ducts to be constructed from galvanized steel, due to the inherent low price of the material, this type of duct is not compatible with the hydraulic fluid used and would result in premature failures. However, uncoated carbon steel, PVC plastic pipe, and aluminum are all categorized by their smooth roughness with an absolute roughness, ϵ, of 0.0001 feet [3] and are fully compatible with Skydrol LD-4. Galvanized steel has an absolute roughness of 0.0003 and can be used in the air friction chart, figure 6.20 [3], to determine the friction loss for that specific duct. With a duct air flow rate of 250 cfm, and a duct size of 6 inches, the corresponding friction loss is 0.35 inches wg/100 feet. A conversion factor is required to obtain representative data for a material in the smooth roughness category and has been found to be 0.9. Therefore, the corresponding friction factor for either three materials is 0.315 inches wg/100 feet. This value will be used to determine pressure losses in various lengths of ducts in our proposed system. Due to PVC plastic pipe not conforming to local building codes, it is recommended that all HVAC ducts are created using aluminum.

2.3. Ventilation Air Supply System

The ventilation air supply system is comprised of ducts and diffusers to distribute the air, and a fan to bring the air into the room at the required flow rate. The following sections show the analysis of sizing and selecting the ducts, selecting the air circulation pattern for the room and the required diffuser, and the selection of the fan type and size.

2.3.1. Ducts and Duct Sizing

The required duct size was then calculated based on velocity recommendations for moderate pressure losses. For smaller ventilation systems, in-duct velocities are recommended to be below 1200 ft/min to keep noise levels and pressure losses relatively low [4], with maximum velocities limited to 2400 ft/min. The recommended velocity of 1200 ft/min was used as a guideline for sizing the main supply duct, as presented below.

$$A = Q/V \tag{5}$$

$$A = \frac{750\ [ft^3/min]}{1200\ [ft/min]} = 0.625\ [ft^2] = 90\ [in^2]$$

$$d = \sqrt{4A/\pi}$$

$$d = \sqrt{4(90)/\pi} = 10.70\ [in]$$

Since the calculated size of the ducts is relatively close to the Select the next larger commercially available size, which is a ten-inch diameter duct. The velocity of the air in the pipe for the ten-inch diameter pipe is calculated using (5).

$$A = \frac{\pi}{4}\left(\frac{10}{12}\right)^2 = 0.545\ [ft^2]$$

$$V = \frac{Q}{A} = \frac{750}{0.545}$$

$$V = 1375\ [ft/min]$$

Although slightly higher than recommended, a velocity of 1375 ft/min is still well below the maximum velocity of 2400 ft/min stated earlier, and thus the ten-inch diameter duct was selected to transport the air between the fan to the tee connected to the first diffuser. Table A- II below provides a summary of the different parts of the supply side of the ventilation system.

TABLE A- II: AIR DUCT SUMMARY

Location	**Diameter of Duct, in**	**Cross-Sectional Area, ft^2**	**Volume of Air, cfm**	**Velocity of flow, ft/min**
Air Intake[1]	20 x 18	1.875	750	400
Air Intake to fan	12	0.7854	750	955
Fan to Heater	10	0.5454	750	1375
Heater to Tee 1	10	0.5454	750	1375
Tee 1 to Tee 2	8	0.3491	500	1432
Tee 2 to Diffuser 3	6	0.1963	250	1273
Diffuser Exit[2]	10 x 6	0.34	250	735

Footnotes:

1. The air intake is covered by a screen that provides 75% open area. Thus, the provided cross-sectional area has incorporated this into the value provided.
2. The cross-sectional area is the open area.

Although the velocities through the ducts are up to 20% higher than the recommended value of 1200 ft/min, noise is not a major concern, and the team would rather specify slightly higher velocities than specify larger ducts due to space constraints in the hydraulic loading room, particularly in the vicinity of the hydraulic loading cabinet where the tubes carrying hydraulic fluid to and from the test engine are located.

2.3.2. Pressure Losses

The pressure losses for the fittings are determined from tabulated values and then calculated based on the average velocity of the flow.

$$\Delta P_0 = C_0 \left(\frac{\bar{V}}{4005} \right)^2 \qquad (6)$$

Where

C_0 = the pressure loss coefficient

$\bar{V}$ = the velocity of the air [fpm]

For a pleated six-inch diameter 90° elbow the pressure loss coefficient is 0.43. The pressure loss through the six-inch diameter elbow is calculated using (6).

$$\Delta P_0 = (0.43)\left(\frac{1273}{4005}\right)^2 = 0.0434\ [in. wg]$$

To determine the pressure losses due to friction in the pipes is dependent on the Reynolds number. The Reynolds number is dependent on the density, velocity, and the dynamic viscosity of the fluid, as well as the diameter of the tube, viz.

$$Re = \frac{\rho \bar{V} D}{\mu} \tag{7}$$

All values were determined for 15°C, and the density and dynamic viscosity of the air were found from[10]. For the ten-inch diameter duct and 750 cfm flow rate, the Reynolds number was determined using (7).

$$Re = \frac{\left(0.07645\,\frac{lbm}{ft^3}\right)\left(1375\,\frac{ft}{min}\right)\left(\frac{10\ in}{12\ in/ft}\right)}{\left(0.04327\,\frac{lbm}{ft\cdot hr}\right)\left(\frac{hr}{60\ min}\right)}$$

$$Re = 121{,}500$$

To get an idea of the losses that occur through the ducts themselves, the friction factor was calculated using the Colebrook formula, viz.

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{e/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right) \tag{8}$$

Where the friction factor is determined through an iterative process. Using a surface roughness value for aluminum of 6.56x10-6 [5], the friction factor turns out to be 0.017, whereas the corresponding friction factor for a galvanized duct is only 15% higher at 0.020. Because the purpose of this analysis is for a quick sizing of components, the tabulated values for the galvanized steel ducts provide a good approximation for the aluminum ducts as well. The friction losses were determined from Figure A-2, using the tube diameters, and corresponding airflow, outlined in Table Table A-III

Figure A-2: Friction losses for galvanized steel ducts [4]

Table A-III presents the frictional losses for the ductwork for the air supply system.

TABLE A-III: FRICTION LOSSES THROUGH DUCTS

Location	Diameter of Duct, in	Volume of Air, cfm	Velocity of flow, ft/min	Pressure Loss, $\frac{in.wg}{100\ ft}$	Duct Length, ft	Pressure Loss, in. wg
Air Intake to fan	12	750	955	0.12	1	0.0012
Fan to Heater	10	750	1375	0.30	3	0.009
Heater to Tee 1	10	750	1375	0.30	3	0.009
Tee 1 to Tee 2	8	500	1432	0.40	5	0.020
Tee 2 to Elbow 2	6	250	1273	0.45	5	0.0225
Total	**-**	**-**	**-**	**-**	**17**	**0.0617**

2.3.3. Diffusers and Air Circulation Patterns

In order to reduce the space claim on valuable floor and wall space, the team placed the supply air ductwork along the ceiling of the trailer. Furthermore, placing the ducts and diffusers along the ceiling helps to reduce the likelihood of fluid contaminants collecting on or entering the ducts. The team then searched for diffuser styles that are compatible with ceiling mounted ducts, selecting round ceiling type diffusers as well as high sidewall type diffusers to compare. The team compared corresponding diffuser styles considering properties such as velocity, throw, pressure loss, and noise created.

The ceiling diffusers were placed in the lateral centre of the room and since the inside width of the room is 11.33 ft, the distance to the wall from the diffuser is 5.67 ft. The characteristic length for a round ceiling diffuser is defined as the “distance to the closest wall or intersecting air jet” [4]. Noting that if three diffusers are selected, the characteristic length reduces from 5.67 feet to five feet due to the intersecting jets that occur when spacing of the diffusers equally along the length of the trailer. The throw-to-length ratio for a round ceiling diffuser is 0.8 for all heating and cooling loads and as a result the throw for the tabulated values are as follows:

$$\frac{x_{50}}{L} = 0.8 \tag{9}$$

$$x_{50} = 0.8(5\ ft) = 4\ ft$$

When using a ceiling diffuser for heating, one of the main concerns is the large stagnant region that develops in the occupied zone when conventional exit velocities are used. Also, as this room will be used for heating, the 150 ft/min velocity needs to extend to within 4.5 feet of the floor [6], especially when the entering air more than 15°F warmer than the air in the controlled space, due to buoyancy effects. Additionally, the diffusers would be placed in the center of the room and as such may cause contaminated air to cycle into the workers breathing zone.

Next, the team considered high sidewall diffusers. Three high sidewall diffusers spaced equally using the spread of 22.5° provides the required 11 feet of throw and provides coverage to the entire room, whereas a similar diffuser at 45° spread runs out of throw before reaching the other side of the room.

Table A-IV provides a performance summary for the selected diffuser. Note that A_c is the cross-sectional area of the diffuser (open area), NC is the noise criterion, and that the minimum, mid, and maximum throws correspond to velocities of 150 ft/min, 100 ft/min, and 50 ft/min, respectively. In order to interpret the results of Table A-IV, the characteristic length must first be determined and multiplied by the throw-to-length ratio to obtain the correct throw for the tabulated values. High sidewall diffusers have a throw-to-length ratio of 1.5 to 1.6 depending on the temperature differential in the room. Selecting the lower throw-to-length value of 1.5 yields a throw of approximately 15 feet to look for in the performance table.

TABLE A-IV: HIGH SIDEWALL DIFFUSER PERFORMANCE DATA, 22.5° SPREAD [4]

Sizes, in	A_c, ft^2	Flow Rate, cfm	Velocity, ft/min	Velocity Pressure, in. wg	Total Pressure, in. wg	NC	Throw, ft		
							Min	Mid	Max
16x4 **12x5** **10x6**	0.34	240	700	0.030	0.058	17	11	16	22
		270	800	0.040	0.078	21	13	18	24

The team selected the high sidewall diffusers for the final design due to the longer throw, and because this diffuser style allowed for the ductwork to be placed along the outside walls of the trailer, providing for a cleaner and more efficient use of space.

2.3.4. Fan Selection for Air Supply System

The pressure losses through the system need to be determined before fan selection can be completed. Table A-V provides a summary of the expected pressure losses for the system.

TABLE A-V: PRESSURE LOSSES FOR THE AIR SUPPLY SYSTEM

Type	Size, in	Total Pressure Loss Coefficient	Airflow, cfm	Average Velocity ft/min	Velocity Pressure Loss, in. wg	Total Pressure Loss, in. wg	QTY	Totals
Reducer	14 - 12	0.027	750	814	-	0.001	1	0.001
Reducer	12 - 10	0.031	750	1136	-	0.002	1	0.002
Reducer	10 – 8	0.036	500	1132	-	0.003	1	0.003
Reducer	8 – 6	0.044	250	935	-	0.002	2	0.004
Reducer	10 – 6	0.064	250	716	-	0.002	1	0.002
Elbow	6 – 6	0.43	250	1273	-	0.043	1	0.043
Diffuser	10 - 6	N/A	250	735	0.0335	0.065	3	0.195
Intake		N/A	750	400	negligible	negligible	1	0
Heating Coil		N/A	750			0.1	2	0.2
Ducts	Varies	-	Varies	Varies	-	-	-	0.0617
Totals								**0.512**

Thus, a fan that can supply 750 cfm of air at 0.512 inches of water gauge pressure should be selected for the air supply system.

3. Heating

This section presents the calculations to determine the required heat load that is required for the hydraulic loading room. The required heat load is determined by calculating the heat losses through the envelop of the building and the heat load required to warm the outdoor air to an acceptable indoor temperature.

3.1. Heat loss calculations

Heat losses through the envelope of the building are due to conduction through the walls, floor, roof and doors and infiltration of air into the building. This section will provide the calculations of the conduction and infiltration heat losses and the resulting total heat loss through the envelope.

3.2. Conduction Heat Losses

The conduction heat transfer equation, (10), was used to approximate the heat losses through the walls, roof and doors.

$$q = UA\Delta T \qquad (10)$$

Where

q = rate of heat transfer [Btu/hr]

U = overall heat-transfer coefficient [Btu/hr-ft^2-˚F]

A = surface area of walls, roof, floor or door [ft^2]

ΔT = difference between indoor and outdoor temperatures [˚F]

The overall heat transfer coefficient is calculated using (11), where R [hr-ft^2-˚F/Btu] is the thermal resistance.

$$U = \frac{1}{R} \qquad (11)$$

The thermal resistance values are determined by the construction materials used to build the envelope of the building. The building selected by the design team was a mobile construction trailer that is 30 feet long and 12 feet wide with a 10-foot ceiling. The trailer, sourced from ATCO, is a custom sized trailer in which custom specified construction can be requested. The thermal resistance values for the walls, roof and floor were sourced from the values specified by the National Energy Code of Canada for Buildings [7]. The resistance values used for the small door and the large double swinging door were based on the average value for steel and fiberglass-clad entry doors [23]. The building envelope thermal resistance values are listed in Table A- VI, along with the calculated heat transfer coefficient using (11).

TABLE A- VI: THERMAL RESISTANCE AND HEAT TRANSFER COEFFICIENTS

Item	Thermal Resistance Value [hr-ft2-˚F/Btu]	Heat Transfer Coefficient [Btu/hr-ft2-˚F]
Walls	20	0.05
Roof	20	0.05
Floor	7.5	0.13
Door	5	0.2

The area of the walls used in the heat transfer calculation are shown in Table A-VII. The dimensions of the small door are 6.7 ft high and 3 ft wide and the dimensions of the large door are 9.5 ft high and 10 ft wide. For naming purposes and infiltration calculations following, Figure A-3 refers to the direction each wall of the trailer is facing.

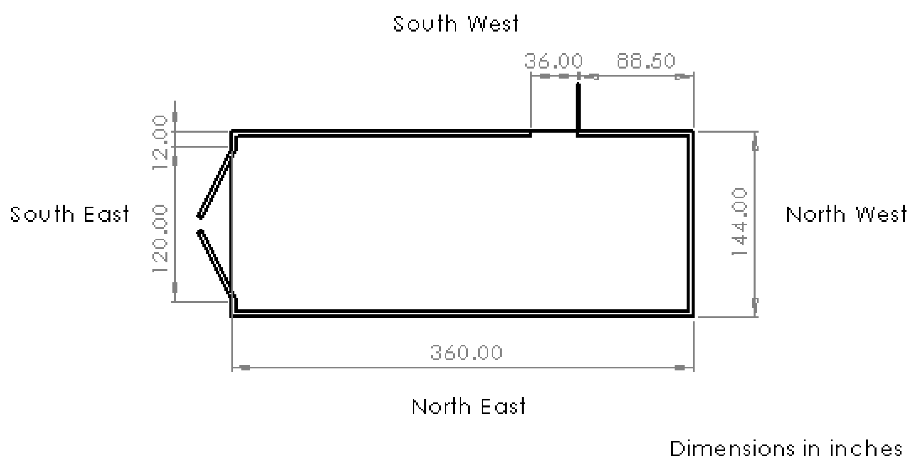


Figure A-3: Facing direction of each wall

TABLE A-VII: AREAS OF BUILDING ENVELOPE COMPONENTS

Item	Area [ft2]
NE wall	300
NW wall	120
SW wall	280
SE wall	25
SW door (small)	20

Item	Area [ft^2]
SE door (large)	95
Floor and roof	360

The outdoor, indoor design temperatures and the resulting temperature difference used in the heat transfer calculation are listed in Table A-VIII.

TABLE A-VIII: DESIGN TEMPERATURES UESD IN HEAT CALCULATIONS

Temperature	Value [˚F]
Indoor	41
Outdoor	-35
ΔT	76

The outdoor design temperature was sourced from the 2005 ASHRAE Handbook – Fundamentals (IP) [8]. The indoor design temperature was selected with consideration of the type of work the employees are conducting in the trailer and the clothing that the employees normally wear. The work performed in the trailer involves connecting and disconnecting hoses, draining hydraulic fluid lines and clean-up of fluid spills. The work was considered to be moderate to heavy work and is usually conducted in winter clothing. A lower design temperature was also desired for the system due to the ventilation requirements of high amounts of outdoor air coming into the space, which must be heated. Heating to a normal sedentary comfortable indoor temperature would result in large heating equipment, which is unsuitable for the design.

A sample calculation, using (10), of the SW wall for heat losses due to conduction is shown below. Table A-IX shows the values for all the walls, doors and the roof.

$$q_{SWwall} = (0.05)(280)(76) = 1064\ Btu/hr$$

TABLE A-IX: HEAT LOSS VALUES FOR WALLS, DOORS, AND ROOF

Item	Heat Loss Value [Btu/hr]
NE wall	1140
NW wall	456
SW wall	1064
SE wall	95

Item	Heat Loss Value [Btu/hr]
SW door (small)	304
SE door (large)	1444
Roof	1368
Total	5871

The conduction heat transfer equation used to calculate the heat loss through the floor is slightly different than (10). The room is on an uninsulated concrete slab, with insulation in the floor of the room above the slab. The significant portion of heat loss is through the perimeter of the floor, where close to the middle of the building the heat loss to the ground is insignificant. (12) is the equation used to calculate the heat loss through the floor around the perimeter of the building.

$$q = U'P\Delta T \tag{12}$$

Where

U′= heat loss coefficient [Btu/hr-ft-˚F]

P = Perimeter of floor [ft]

ΔT = difference between indoor and outdoor temperatures [˚F]

The heat loss coefficient, U’, is determined using Figure A-4, where the x axis is the heat transfer coefficient per unit area, U, and the y axis is the heat transfer coefficient per unit length, U’. The data was not available for 0.13 Btu/hr-ft^2-˚F, thus the closest value of 0.15 was used.

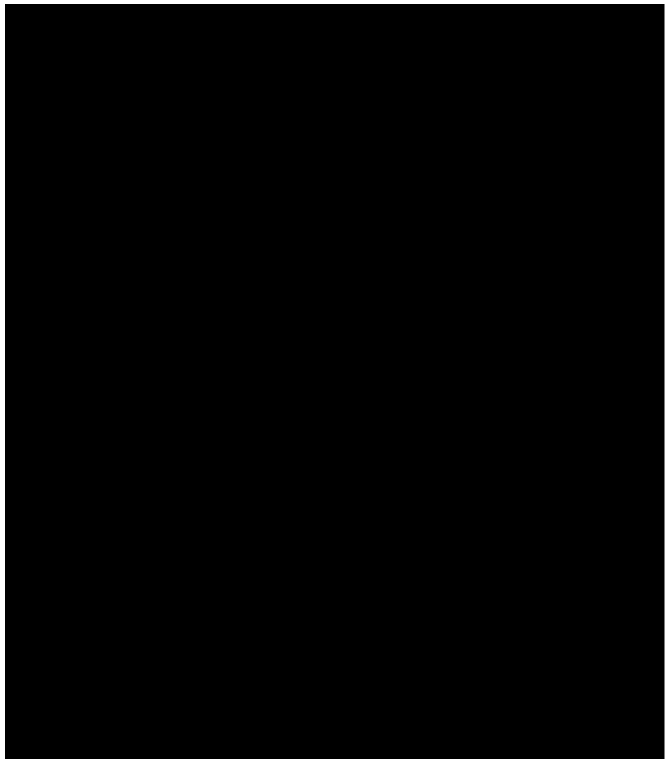


Figure A-4: Heat loss factors for slab floors on grade [9]

From Table A-VIII, assuming the insulation is 3 feet in from the external wall, U' is approximately 0.71 Btu/hr-ft-˚F. The perimeter of the room is 84 feet and the difference in temperature is 76 ˚F. The perimeter heat loss calculation, using (12), is as follows:

$$q = (0.71)(84)(76)$$

$$q = 4533\ Btu/hr$$

The total heat loss due to conduction is 10,400 Btu/hr. Conduction heat losses are combined with the infiltration heat losses resulting in the total over all heat loss.

3.3. Infiltration Heat Losses

Infiltration heat losses were approximated using the crack method. This method approximates how much air comes in through cracks around the doors, based on how tight the door is fitted and the average weather conditions in Thompson. MB. The heat transfer due to infiltration is calculated using (13).

$$q = \dot{Q}(60)c_p\rho\Delta T \tag{13}$$

Where

q = rate of heat transfer [Btu/hr]

$\dot{Q}$ = volume flow rate due to wind [ft^3/min]

c_p = constant-pressure specific heat of air [Btu/lbm-˚F]

ρ = density of air [lbm/ft^3]

The volume flow rate is determined by first calculating the pressure difference in the building due to the wind, with (14).

$$\Delta P_w = \frac{(0.19) C_p \rho \bar{V}_w^{\,2}}{2 g_c} \tag{14}$$

Where

ΔP_w= pressure difference due to the wind [in of wg]

C_p = average wall pressure coefficient

ρ = density of air [lbm/ft^3]

$\bar{V}_w$ = Velocity of wind [ft/s]

g_c = dimensional constant, 32.17 [lbm-ft/lbf-s^2]

Table A-X shows the values used for the pressure difference calculation and the source.

TABLE A-X: VALUES FOR PRESSURE DIFFERENCE CALCULATION

Variable	Value [unit]	Source
C_p	0.3	[11]
ρ @ -35˚F	0.0912 [lbm/ft^3]	[24]
$\bar{V}_w$	26.7 [ft/s]	[25]

The pressure difference due to the wind is calculated using (14) as shown:

$$\Delta P_w = \frac{(0.19)(0.3)(0.0912)(26.7)^2}{2(32.17)} = 0.058\ in\ of\ wg$$

Figure A- 5 was then used to determine the infiltration volume flow rate per length of crack, based on how tight the doors are fitted, denoted by K. The K value was based on an average fitting door with weather stripping, equal to 2 [11].

Figure A- 5: Window and door infiltration characteristics [9]

From Table A- XI, the infiltration volume rate per length of crack is equal to 0.3 ft^3/min-ft. With a length of crack from summing the perimeter of both doors and the center seam of the large swinging door equal to 81.3 feet, the volume rate due to infiltration is 28.5 ft^3/min. The heat loss due to infiltration is calculated using (13). The variables used in the equation are listed in Table A- XI, preceding the calculation.

TABLE A- XI: VALUES FOR INFILTRATION HEAT LOSS CALCULATION

Variable	Value [unit]
$\dot{Q}$	28.5 [ft^3/min]
c_p	0.24 [Btu/lbm-˚F] [11]
ρ @ -35˚F	0.0912 [lbm/ft^3] [24]
ΔT	76 [˚F]

$$q = (28.5)(60)(0.24)(0.0912)(76) = 2845\ Btu/hr$$

Summing the losses due to conduction and infiltration, the total heat losses through the envelope of the building is 13,250 Btu/hr.

3.4. Heat Load Calculations

The heat load calculation is the energy required to heat the outdoor air to an acceptable indoor design temperature. Using (13) , the heat load was calculated. Using (13), the heat load was calculated. The values used for the calculation are the same as the infiltration heat loss calculation, found in Table A- XI, apart from the volume flow rate. The volume flow rate used in this calculation is the flow rate of the ventilation system, which is 750 ft^3/min. The heat load calculation is as follows:

$$q = (750)(60)(0.24)(0.0912)(76) = 74857\ Btu/hr \cong 75000\ Btu/hr$$

The heat losses through the envelope and required energy to heat the outdoor air to 41 ˚F (5˚C) are combined resulting in the total energy that the heating system must provide. The resulting total heat load is 88,250 Btu/hr approximately equal to 26 kW.

4. References

[1] Eastman Chemical Company, "Safety Data Sheet: Skydrol LD4 Fire Resistant Hydraulic Fluid," 06 02 2015. [Online]. [Accessed 05 10 2019].

[2] ASHRAE, 2011 ASHRAE HANDBOOK: Heating, Ventilating, and Air Conditioning Applications, Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 2011.

[3] R. W. Haines and M. E. Myers, HVAC Systems Design Handbook: Fifth Edition, McGraw Hill, 2010.

[4] F. C. McQuiston, J. D. Parker and J. D. Spitler, Heating, Ventilating and Air Conditioning: Analysis and Design 6th Edition, Hoboken, New Jersey: John Wiley & Sons, Inc., 2005.

[5] Engineering Toolbox, "Roughness & Surface Coefficients," 2003. [Online]. Available: https://www.engineeringtoolbox.com/surface-roughness-ventilation-ducts-d_209.html. [Accessed 28 November 2019].

[6] D. Int-Hout III, "Best Practices for Selecting Diffusers," June 2004. [Online]. Available: https://www.krueger-hvac.com/files/white%20papers/article_diffuser_selection.pdf. [Accessed 18 November 2019].

[7] Canadian Commission on Building and Fire Codes, National Reseach Council of Canada, "National Energy Code of Canada for Buildings 2017," National Research Council of Canada, Ottawa, 2017.

[8] ASHRAE, "Design conditions for THOMPSON AIRPORT, MB, Canada," 2005. [Online]. Available: http://cms.ashrae.biz/weatherdata/STATIONS/710790_p.pdf. [Accessed November 2019].

[9] V. Asikainen and P. Pasanen, "The Prevention of the Snow Entrance to the HVAC-systems," in Proceedings of the Clima 2007 WellBeing Indoors, Helsinki, Finland, 2007.

[10] Engineering Toolbox, "Air - Density, Specific Weight and Thermal Expansion Coefficient at Varying Temperature and Constant Pressures," 2003. [Online]. Available: https://www.engineeringtoolbox.com/air-density-specific-weight-d_600.html. [Accessed November 2019].

B. Appendix – Concept Generation and Selection

Table of Contents

List of Figures

List of Tables

1. Introduction

This appendix contains the details of concept generation and selection phase of our design process. This phase is organized into sub-sections pertaining to the equipment layout, heating, ventilation, spill prevention and collection systems. This analysis resulted in the selection of one layout and two solution possibilities for each category of heating, ventilation, spill collection and spill containment. These selections are carried forward into the final report section of this document for further analysis and optimization.

2. Concept Generation

For generating concepts, the team separated the main design requirements needed for a complete overhaul of the hydraulic loading room. These requirements included facility layout, spill prevention, spill containment, heating and ventilation. Research on existing design solutions for each of the systems was conducted and brainstorming sessions were held. The methodology behind concept generation was to break down the size of the project into more manageable sections, according to each of the main requirements. The split sections allowed the team to come up with many different possible solutions and compile the best system for this application. Each of the following sub-sections document the possible solutions the team suggested for each of the main requirements of the project.

2.1. Facility Layout Concepts and Selection Criteria

To improve on the current layout, the team set out to identify and compile criteria that a design improvement would need to satisfy. The four criteria identified are as follows:

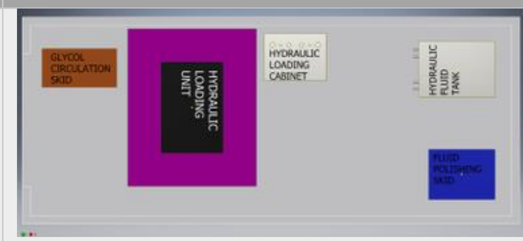
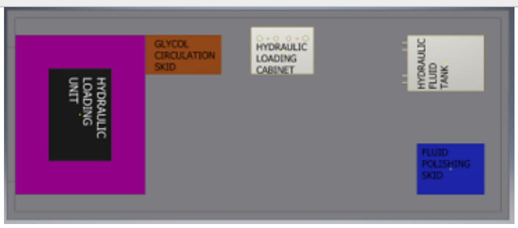
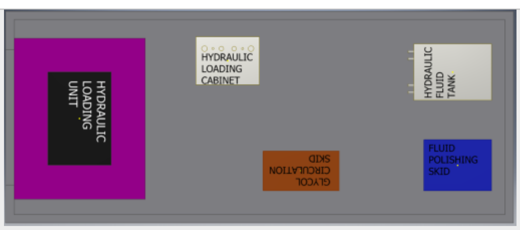
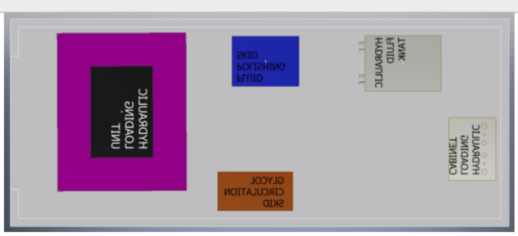
Ease of installing HLU: The process of installing and removing the hydraulic loading unit should require the least amount of operations possible in order to increase time efficiency during testing (need 1.1).

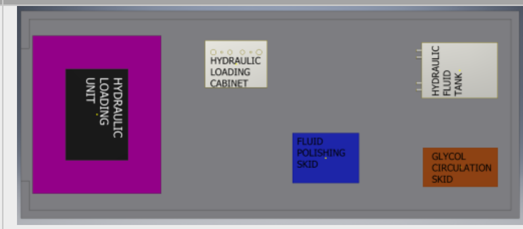
Walkway square footage: The final design layout will limit equipment placement that would obstruct operator movements trough the room. This criterion represents a measure of the anticipated unobstructed area in which operators can work (need 1.2).

Hose organization: Hoses in the room should be kept neatly organized and seek to avoid crossing walkway areas where they can pose as tripping hazards (need 6.3).

Ease of equipment accessibility: 360-degree access to elements of the equipment, particularly the hydraulic loading unit and glycol hose connections should be maximized while adhering to the aforementioned criteria (need 1.2).

TABLE B-I: PLAUSIBLE LAYOUT ITERATIONS

Label	Concept Image	Description
A		This concept centers the HLU between the glycol skid and hydraulic loading cabinet. This is done in order to ensure short hose connections that don't traverse the main walkways.
B		This concept's distinguishing features are the positioning of the HLU at the large door entrance and the glycol skid next to it. During testing this setup would only require hoses running along the one side of the room.
C		Similar to concept B, this concept also has the HLU positioned at the large door, however it places the glycol skid on the other side of the room. During operation the hoses would run along the periphery of the room and away from the walkway.
D		This concept is the most radical in that it moves the location of the loading cabinet to the back wall of the room. Moving the loading cabinet requires a reconfiguration of the external hydraulic lines which could be costly and time-intensive.

Label	Concept Image	Description
E		This concept is similar to B and C except that it places the glycol skid on the opposite end of the room. The increased distance between the HLU and glycol skid help to prevent potential spills at the glycol skid connection points from mixing with hydraulic fluid.

All the designs considered by the team, featured in Table B-I, are based on a room with two extra feet of width over the current configuration. This improved equipment accessibility and operator walkway square footage.

2.2. Spill Prevention System

Unlike other sub-systems, spill prevention was not an explicit requirement for this project. However, our group's logic was that additional measures of spill prevention would be a great way to reduce the need for an elaborate spill containment system. In other words, the best method for spill containment is spill prevention. The potential system concepts our team generated for spill prevention are as follows:

Raised Cabinet with Hydraulic Drain

One possible spill prevention concept that could reduce the number of spills in the hydraulic loading room is an added drain at the bottom of the spill trough that is already positioned underneath the hydraulic loading cabinet. For this drain concept to work, the hydraulic loading cabinet would have to be raised one to two feet so that the trough would be at waist height for most employees. Additionally, the drain would be installed such that it is in line with a storage tank or barrel so that hydraulic fluid could flow freely from the trough to secondary storage. This concept requires reconfiguration of permanent, steel hydraulic lines so the concept could be costly to implement. However, the system components themselves are relatively inexpensive. Some issues with this concept are that fluid is still prone to splash out of the spill trough when draining hydraulic lines. Employees may also be exposed to the hydraulic oil when manually cracking hydraulic lines. Additionally, this concept would require an open-faced barrel, so contaminants are likely to enter the air and fluid.

Raised Cabinet with Hydraulic Drain Line

Similar to the previous concept, major fluid spills could be avoided by raising the height of the hydraulic loading cabinet. However, instead of relying on a gravity drain to direct the flow of hydraulic fluid into a storage barrel, a drain line could be used to reduce the amount of contaminants that are exposed to both the air and fluid. It should be noted that this concept shares many of the same qualities and expenses as the first concept.

Flow Divider

A flow divider is a hydraulic device that is typically used for dividing a flow of hydraulic fluid into separate streams. This device is particularly useful when it is desirable for a single pump to simultaneously power more than one circuit. There are two types of flow dividers available including a spool-type and gear-type. A spool divider housing consists of an inlet and outlet port as well as an internal moveable spool which features cross-drilled holes through the mid-section to control the flow of fluid. Whereas a gear-type divider can split the flow of fluid into two or more paths by means of fluid forces on gear teeth. That is, as the gear teeth mesh, fluid is pushed out of each outlet port. It is also possible to use a proportional flow divider in which the flow to the "control flow" and "exhaust flow" can be manually set.

Using this approach, the control flow could be set to 100% for the duration of the test but would be lowered after the test is complete to drain the fluid through the exhaust flow port. There are currently flow dividers that are rated for an input flow of 5000 psi and 60 gpm, which makes this a viable option.

Multi-Spool Valve Block

A multi-spool valve block can be installed in line with the pressure, suction, and case drain lines to serve as a possible spill preventative measure. Like the flow divider, spools are located at each valve and can be controlled with the use of a mechanical lever or electrical solenoid. This hydraulic component could benefit MDS AeroTest since the mechanical levers could be used to redirect the flow of fluid from the hydraulic loading cabinet to a secondary storage source, such as the hydraulic tank. The schematic for a double spool valve block can be seen in Figure B-1. It is important to note that this valve block features an open-centre design which allows fluid through the spool when the lever or solenoid is in the default position.

Figure B-1: Hydraulic schematic for double-spool valve block [1]

Hydraulic Quick Couplers

Push-pull quick connect couplings are a highly effective method for reducing spills in an assortment of industries. These hydraulic components allow for easy connection and disconnection of hydraulic lines and are especially growing in civil and military aircraft applications. This type of concept would allow employees to disconnect the pressure, suction, and case drain lines at the hydraulic loading cabinet without having the need for draining each line first. This would save employees countless hours and would completely eliminate hydraulic fluid spills and hazards. Both Parker and Eaton manufacture quick couplers which are readily compatible with Skydrol LD-4. However, the hydraulic quick couplers must be able to operate in conjunction with the appropriate flow rate and pressure settings required by either Rolls Royce and Pratt and Whitney.

T-fitting with Gauge Port and Auxiliary Bleed Line

The last concept that was generated for spill prevention systems was the use of a T-fitting with gauge port used in conjunction with an auxiliary bleed line. This system would operate by installing the T-fitting in line with the main pressure line at the hydraulic loading cabinet. The gauge port would be threaded into the T-fitting to set up a parallel network of hydraulic lines. It would be desirable for the gauge port to have an option of quick coupling so that the auxiliary bleed line could be connected whenever a hydraulic line needs to be drained. Using a quick coupler for the gauge port also allows MDS AeroTest personnel to connect specialty instrumentation which could be used for system monitoring and fluid sampling. Since the auxiliary line would be connected in a parallel configuration, no additional flow restrictions would be introduced in the system, which makes this concept very attractive.

2.3. Spill Containment System Design Concepts

The concepts for the spill containment system generated by the team are as follows;

Troughs at All Connection Points

Inserting a trough at each of the connection points located throughout the hydraulic loading room will allow for fluid collection whenever a hydraulic line or glycol line is disconnected. This concept is the current method of spill containment and has been shown to provide a satisfactory means of containing spills. This concept has been illustrated in Figure B-2.

Figure B-2: Hydraulic spill collection tray [2]

Evidently, this method only encompasses spills that exist in the immediate vicinity of equipment and does not contain spills that may occur at a distance from each piece of equipment. In total, there is one spill collection tray placed in front of the hydraulic storage tank and one other spill trough directly in line with the hydraulic loading cabinet. All other pieces of equipment are located on liftable-skids which also provide some means of fluid containment. That being said, these skids must often be cleaned of hydraulic fluid. A spill collection tray can only hold a couple liters of fluid and must be drained manually by employees. Absorbent pads are often placed in the spill collection tray to soak up the chemicals and must be discarded in the solid waste disposal, separate from the fluid disposal.

Gradient Floor with Grates

One possible solution that could remedy the spill containment issue MDS AeroTest is experiencing is to implement a system of floor grates into the hydraulic loading room. Fluid spills would either drain through the grates on their own or need to be squeegeed into the grates manually. Once fluid is collected in the grates, a secondary floor underneath the grates would allow the fluid to drain into the appropriate sump. Fluid would be collected into the sump by means of a gravity-induced flow along a floor gradient, or slope. Additionally, fluids spills could be separated by having multiple floor gradients depending on where the floor grates are located. This would essentially allow glycol to drain on one gradient and hydraulic fluid to drain on another gradient, into sumps. In order to drain the fluid from the sump, a gravity drain, or sump pump could be used to ease this process.

Perforated Floor Grating

Another alternative to spill containment systems is to replace the floor of the hydraulic loading room with perforated aluminum floor grates. This style of floor grate is superior to normal floor grates since the round holes would not interfere with the caster wheels of large equipment, such as an HLU. In conjunction with perforated floor grates, a storage basin or sump would be implemented underneath the floor grates to catch hydraulic fluid as it is spilled. This approach to spill containment is highly effective at collecting spills. However, since the floor grate would also act as a walking path for employees, there would be a greater likelihood of contaminants and outside debris entering the fluid containment system.

Spill Pallets

Spill pallets are commonly found in large facilities and workspaces to serve as a means of secondary containment for fluid storage vessels. Due to their large fluid and load capacities, the spill pallets are an attractive choice for spill containment and can be used for many different applications. As an example, a 4-drum capacity spill pallet has been illustrated in Figure B-3.

Figure B-3: 4-Drum spill pallet [3]

As shown in Figure B-3, the spill pallet features a removable non-skid polyethylene grate. Both this component and the molded-in sumps are chemical and corrosion resistant. It should also be noted that this concept is modular and highly portable. That is, multiple spill pallets can be rearranged to form larger spill containment areas. In the case that the HLU being used is placed outside, the spill pallets could also be relocated to provide spill containment outside.

Floor Drains

There are several different drain configurations which could be used for the hydraulic loading room configuration. This concept would require multiple drains be located near areas of frequent fluid spills, especially local to the various pieces of equipment. One drainage system, namely the *Slot Drain,* incorporates a low-profile slot in the floor to drain any fluid on the surface into an ulterior storage tank or sump. The Slot Drain system drains fluid from the surface into an ulterior tank or sump. Since the drain is a low-profile slot, it is unlikely that this system would impede the process of moving the HLU around the room. It should also be noted that this system has a self-cleaning feature which would clean the whole drainage system without any additional measures.

Garage Barriers

The last of the spill containment concepts is a type of containment berm, or *Garage Barrier* as *Ultratech* has named it. The Garage Barrier is constructed of rugged 18 oz. PVC with a one-inch-high barrier around the object's perimeter to retain fluid and debris. This concept has been illustrated in Figure B-4, however it should be noted that the Garage Barrier is available in a variety of shapes and sizes.

Figure B-4: Garage barrier concept [4]

As the name suggests, the Garage Barrier shown in Figure B-4 is commonly used in small workshops or garages to prevent any chemicals from spilling out of cars and onto the garage floor. However, the Garage Barrier can hold up to 86.5 gallons [5] of fluid which makes this concept a feasible option for the hydraulic loading room. It should also be noted that this concept is highly transportable and can be folded in a matter of minutes for ease of storage.

2.4. Heating System Design Concepts

The current heating system relies on electric baseboard heaters which allows hydraulic fluid to settle on the surface, be it from spilled hydraulic fluid or the fluid that is vaporized in the air via the HLU. The main problem with the current heating system is when the heater is turned on, this settled fluid is re-vaporized into the air, increasing hazards to employees. The heating system concepts were generated with the issues of the current system in mind. When considering heating options, the hazard of re-vaporization was sought to be mitigated or avoided all together. Additionally, due to the size constraints of the room layout, the heating equipment should be logically placed to avoid wasted space.

This section will present all heat generation concepts that were considered for the hydraulic loading room. The different concepts proposed for the heating system are as follows;

Forced Air Heater Mounted on Ceiling

A forced-air heater unit is a compact heater that can circulate hot air throughout the room and can be mounted anywhere on the ceiling.

This type of heater can be purchased in many different sizes, delivering a range of heat capacities to work with the ventilation system. These types of heaters can also be wired to an external thermostat, to allow for remote-control of the system. The advantage to this concept is that the system is raised off the floor, thus reducing the chance of hydraulic fluid from contacting the heater. Additionally, this concept is a relatively inexpensive option and can be located where it is easily accessible to maintain.

A disadvantage to this heating system is the heating coil is still exposed to the air, where vaporized hydraulic fluid can build up on. Depending on the temperature that the heating element reaches, the hydraulic fluid may re-vaporize into the air. However, it is likely that the baseboard heater system would accumulate a greater amount of fluid when compared to a forced-air heater system.

In-Floor Radiant Heat and In-Wall Radiant Heat

This system is comprised of running electric or hydronic heating coils under the floor or in the wall. Many different types of floor and wall finishes can be applied to cover the heating coils. A floor finish that would work well this application would be an epoxy resin flooring, which is an efficient medium for heat transfer as well as provide a slip resistant surface.

Radiant heating was selected as a concept for the hydraulic loading room mainly due to the low temperature of the heating surface. Keeping the heating surface temperature low is beneficial as this prevents the re-vaporization of hydraulic fluid. In considering the layout space constraints, the radiant heating system built into the floor or into the wall prevents obstruction of floor area, keeping the layout as open as possible.

A disadvantage of radiative heating is that it has a slow response time. Radiant heating also has a higher initial investment cost relative to most other concepts presented in this section. Additionally, because radiant heating systems are enclosed in the wall or floor, they are difficult to access for maintenance or replacement.

Infrared Heater

Infrared heaters are comprised of heating elements that emit infrared radiation. The heater warms objects in the path of the emitted rays, the warmed objects in turn heat the environment around the objects via radiation. This type of heater is inexpensive and quickly heats objects. It is compact and can easily be mounted on the wall or ceiling. This is beneficial in using the space optimally and decreasing the probability of hydraulic fluid being spilled on it.

The disadvantages of this type of heater is that the heating element is exposed and gets extremely hot, thus if vaporized hydraulic fluid settles on the elements, re-vaporization will occur. Another disadvantage is that this type of heater only warms objects quickly, not the air in the space meaning slower temperature response time and limited temperature control of the space. The heater will also only heat objects in its line of sight, requiring multiple heaters to sufficiently heat the space.

Furnace

Another possible concept could be the integration of a furnace into the same ductwork as the ventilation system. A furnace in this small of space will heat the room quickly and give exceptional temperature control via a thermostat. The furnace could be wall mounted, such that it does not interfere with equipment placement. For a furnace type heating system, the heating element is enclosed and protected, preventing re-vaporization of hydraulic fluid.

A disadvantage of the furnace concept is that it is fairly expensive, however working it into the ductwork used for the ventilation system will potentially reduce the cost.

Panel Radiator

The panel radiator is very similar to the in-wall radiant heating concept but differs such that it is not enclosed within the wall.

Similar to in-wall radiant heating, the low surface temperature reduces the possibility of re-vaporizing hydraulic fluid. The panel radiator is cost efficient and is easy to install compared to the in-wall radiant heating system.

Panel radiators only have a small surface area providing radiant heat, compared to the whole wall for in-wall radiant heating. This limits the ability of obtaining even temperature distribution throughout the room and limits the ability to control the overall room temperature. To efficiently heat the space, the mounting location would have to be low to the ground, causing the problem of potentially getting hydraulic fluid spilled on it. This also reduces the limited floor space available for the equipment.

2.5. Ventilation System

The aviation industry requires the use of fire-resistant hydraulic fluids to protect the aircraft from fires in the event of a component failure or fluid leak. For this reason, phosphate ester based hydraulic fluids were developed in the late 1940’s [6] and have been used in the aviation industry ever since. Skydrol LD-4 was introduced in 1978 and is still one of the leading hydraulic oils in use today.

Although fire resistant fluids greatly reduce the occurrence of aircraft fires due to failed hydraulic components, the fire resistance does not come without its share of challenges. For example, tributyl phosphate makes up 55-65% of Skydrol LD-4 hydraulic fluid by concentration [7] and is the main contributor to the fluid’s corrosiveness to many of the materials used in automotive, agricultural, and construction equipment. Tributyl phosphate is also the main contributor to the slight toxicity toward humans.

Phosphate ester-based hydraulic fluids such as Skydrol LD-4 require engineering controls, breathing personal protective equipment (PPE), or both, in order to stay below the recommended exposure limits when working with the fluid. The material safety data sheet for Skydrol LD-4 aviation grade hydraulic fluid states that typically ten air changes per hour provides adequate ventilation to stay below the maximum exposure limits [7]. The team will use the ten air changes per hour as a starting point for sizing the ventilation system and will determine during the final design phase if this number is reasonable for the setup that we have. The team generated five potential design solutions for the ventilation requirements, namely.

Local Exhaust Ventilation

Local exhaust ventilation (LEV) is often the most effective method for the removal of contaminants from a localized area. LEV is extremely effective at removing airborne contaminants when the contaminants are from a definite area or source. LEV uses a fan placed upstream of the ductwork to draw air into a hood that is placed near the source of contaminant generation.

To implement LEV in the design of the hydraulic loading room the team would place the fume hoods near the main sources of fluid leaks, which include the hydraulic loading cabinet and hydraulic loading unit. Ideally, the fume hoods would be adjustable and moveable throughout the hydraulic loading room so that the fume hood could be easily positioned and adjusted such that maximum protection for the workers is achieved.

Dilution Ventilation

Another type of ventilation that is commonly used in industry is general industrial ventilation (aka dilution ventilation). Dilution ventilation provides a constant flow of fresh air to the worker(s). Often dilution ventilation does not completely remove the contaminated air but supplies critical areas with clean air and mixes the remainder to dilute the contaminants to below the acceptable exposure limits of the controlled substance.

To implement general industrial ventilation as a possible solution the team would place diffusers and ductwork preferably inside the wall of the room and strategically place the diffusers to promote airflow to the locations of the hydraulic loading cabinet, HLU, fluid polishing skid, hydraulic tank, as well as the glycol circulation skid. The location of the diffusers as well as the targeted airflow patterns will largely depend on the layout chosen

A second concept for dilution ventilation includes the heating of the air with the ventilation system. This would allow for greater adjustability of the temperature and ventilation rates of the room as both temperature and ventilation rates would not be affected by each another.

Displacement Ventilation

Displacement ventilation relies on the buoyancy of the air to drive the ventilation and air distribution process. Cooler air is injected at the lower areas of the room and the warmer air is evacuated near the ceiling of the room. Because displacement ventilation relies on buoyancy to remove contaminants from the area, it is best suited when the fumes are lighter than air [8].

Industrial Fan Setup

The concept of using industrial fans to provide airflow to areas of the room most in need of airflow. The major benefit to this setup is that it could be implemented in such a way that it is highly mobile and adjustable. Fans could be placed at openings in the trailer and the fans turned on manually when testing or test preparation is in progress.

3. Concept Analysis and Selection

In this section, the concepts for heating, ventilation, layout and spill containment and prevention defined earlier in this report will be evaluated with screening and weighted decision matrices. Unless otherwise noted, the concepts that scored the highest in the concept scoring matrix will be further developed in the final design phase of this project.

3.1. Spill Prevention System

The criteria and justifications established for the spill prevention system rating are as follows;

Prevents a large amount of fluid spills refers to the system's ability to reduce the amount of hose connections being disconnected. The likelihood of a spill can be reduced by eliminating the need for "cracking" hydraulic lines when the HLU is to be removed from the room (need 3.2).

Ease of draining hydraulic fluid at hydraulic cabinet refers to how easy it is for the proposed system to drain the pressure, suction, and case drain lines at the hydraulic loading cabinet. Since all three lines must be drained at the hydraulic cabinet, there is a greater chance for spills to occur. This can be remedied by eliminating the need for hoses to be drained or by making this process more efficient to complete (need 3.2).

Allows for easy transfer of fluid after drainage can be defined as the system's ability to transfer volumes of fluid that would have instead been drained into a trough or spilled on the floor. Therefore, it is also important for the spill prevention system to be able to reliably transfer fluid away from the hydraulic loading cabinet to another barrel or the storage tank that is already in place. There is no explicit need for this criterion, however we determined this was important to MDS AeroTest employees.

Prevents fluid contamination means the spill prevention system must be able to mitigate the risk of spills and keep the fluid from getting contaminated. The system should be able to prevent any sort of exposure to the fluid, but if draining is required, it should be done so in a way that does not introduce any contaminants or debris (need 2.3).

Maintains HLU operability refers to how well the system can be implemented into the hydraulic loading room without affecting the hydraulic fluid pressure and flow rate going to and from the test engine's pump. Both stakeholder companies require that the proposed system does not introduce any restrictions on the main pressure line leading to the hydraulic loading cabinet and minimal pressure losses. Since the main pressure line contains fluid at both a high pressure and flow rate, it is critical that the flow of fluid remains as uninhibited as possible to prevent damage to test equipment (need 3.1).

Reduced work required for setting up HLU describes the system's ability to limit or decrease the amount of work that is required of MDS AeroTest personnel to set up the HLU for testing. This pertains to installing hydraulic lines and glycol hoses, as well as any other work that is required once the HLU is already in place (need 1).

Compatibility of layout refers to how well the spill prevention system can be installed in the hydraulic loading room without having any negative impacts on the proposed layout. This system should be able to operate independently but may require extra instrumentation to work. Therefore, the amount of space that is consumed should be limited and have a logical explanation. Our group decided that this criterion should be included to ensure that the selected spill prevention system is compatible with the layout that is chosen.

Does not impede ease of HLU installation can be thought of as the system's ability to be implemented into the hydraulic loading trailer without interfering with the process of installing the HLU. An effective system should allow the HLU to be installed with ease (need 1.1).

Spill collection compatibility refers to how complimentary the spill prevention system is with the spill collection system. An effective system will either work in conjunction with the proposed spill collection system or work independently without any negative effects on the spill collection system.

Cost of prevention system refers to the monetary value associated with purchasing the system components as well as any additional costs that the client might incur due to installing the components. Since the cost required for installation would only be an approximate value, the concepts will be weighed based on the purchasing price of each system. Our group decided this criterion was important to consider but should not have much weight since it does not appear in the customer needs.

Mitigation of hazards to employees refers to how well the system eliminates or prevents hazards to employees working in the vicinity of the spill prevention system. Common hazards related to the hydraulic loading cabinet involve workers getting sprayed by hydraulic fluid or getting hydraulic fluid on their hands when disconnecting hydraulic hoses (need 6).

Spill prevention criteria were added to the criterion weighting matrix shown in Table B- II and our team compared the relative importance of each criterion. This resulted in the assignment of weights to the selection criteria which were then used to conduct a weighted ranking of the potential design concepts. This analysis is seen in Table B-III.

TABLE B- II: SPILL PREVENTION SYSTEM CRITERION WEIGHTING MATRIX

Spill Prevention Criteria		Prevents a large amount of fluid spills	Ease of draining hydraulic fluid at hydraulic cabinet	Allows for easy transfer of fluid after drainage	Prevents fluid contamination	Maintains HLU operability (functionality)	Reduced work required for setting up HLU	Compatibility of layout	Does not impede ease of HLU installation	Spill collection compatibility	Cost of prevention system	Mitigation of hazards to employees
Criteria		**A**	**B**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
A	Prevents a large amount of fluid spills		A	A	A	F	A	A	I	A	A	L
B	Ease of draining hydraulic fluid at hydraulic cabinet			D	B	F	B	B	I	B	B	L
D	Allows for easy transfer of fluid after drainage				E	F	G	D	I	D	D	L
E	Prevents fluid contamination					F	G	H	I	E	K	L
F	Maintains HLU operability (functionality)						F	F	F	F	F	L
G	Reduced work required for setting up HLU							H	I	G	G	L
H	Compatibility of layout								I	H	H	L
I	Does not impede ease of HLU installation									I	I	L
J	Spill collection compatibility										J	L
K	Cost of prevention system											L
L	Mitigation of hazards to employees											
Total Hits		7	5	4	2	9	4	4	8	1	1	10
Weight		0.13	0.09	0.07	0.04	0.16	0.07	0.07	0.15	0.02	0.02	0.18

TABLE B-III: SPILL PREVENTION WEIGHTED DECISION MATRIX

Spill Prevention		Concepts												
			Raise cabinet with bin under		Raise cabinet - line going to barrel or back to tank		Flow divider - redirecting flow from HLU to container or tank		2-way open centre valve block		Quick connect couplers on hydraulic lines		Auxiliary bleed line off main pressure line	
Selection Criteria		Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Prevents a large amount of fluid spills	0.127	2	0.255	3	0.382	5	0.636	5	0.636	4	0.509	5	0.636
B	Ease of draining hydraulic fluid at hydraulic cabinet	0.091	2	0.182	2	0.182	3	0.273	4	0.364	4	0.364	5	0.455
C	Allows for easy transfer of fluid after drainage	0.073	2	0.145	3	0.218	3	0.218	3	0.218	5	0.364	3	0.218
D	Prevents fluid contamination	0.036	3	0.109	3	0.109	4	0.145	4	0.145	5	0.182	4	0.145
E	Maintains HLU operability (functionality)	0.164	5	0.818	5	0.818	3	0.491	3	0.491	1	0.164	4	0.655
F	Reduced work required for setting up HLU	0.073	1	0.073	1	0.073	1	0.073	1	0.073	5	0.364	1	0.073
G	Compatibility of layout	0.073	4	0.291	4	0.291	4	0.291	4	0.291	4	0.291	4	0.291
H	Does not impede ease of HLU installation	0.145	5	0.727	5	0.727	5	0.727	5	0.727	5	0.727	5	0.727
I	Spill collection compatibility	0.018	5	0.091	5	0.091	5	0.091	5	0.091	5	0.091	5	0.091
J	Cost of prevention system	0.018	2	0.036	2	0.036	4	0.073	3	0.055	1	0.018	4	0.073
K	Mitigation of hazards to employees	0.182	1	0.182	1	0.182	3	0.545	3	0.545	4	0.727	3	0.545
	Total Score			2.91		3.11		3.56		3.64		3.80		3.91
	Rank			6		5		4		3		2		1
	Continue?			No		No		No		No		Yes		Yes

From Table B-III, our group was able to conclude that the auxiliary bleed line off the main pressure line was the most practical solution to a spill prevention system. Although this concept scored the highest, our group has decided to present a more in-depth trade-off study of the higher ranked concepts in the final design report. Therefore, the quick connect couplers concept will also be assessed.

3.2. Spill Containment System

The criteria and justifications established for ranking the potential spill containment systems are as follows:

Cost of system refers to the monetary value of the system as well as the approximate cost that the client would incur for implementing each of the concepts to fit the hydraulic loading room. Since the cost of installing different systems is somewhat subjective, this value will be determined by assessing the complexity of each concept.

Ease of fluid drainage refers to the system's ability to drain hydraulic fluid and glycol after the fluid has been collected. For many of the concepts generated, our group will evaluate how the system's storage sump or catch basin can be drained. A concept will score higher if the system does not require employees to manually empty drainage tanks. This need was identified after creating the list of client needs, and is therefore included in this list of selection criteria.

Ease of cleaning spill containment systems refers to how easy each system is to clean once the fluids have already been drained from the sump or storage basin. Since MDS AeroTest requires a clean environment in order to complete hydraulic loading tests, it is critical that each spill containment system is easily accessible for employees to complete a thorough cleaning (need 2.4).

Ability to retain fluid without contaminants refers to how well the system can contain fluids without collecting additional foreign objects and debris, especially when employees must complete maintenance inside the hydraulic loading room. Debris including dirt, snow, and water should be prevented from entering the spill containment system so that the client can retain the ability to recycle the fluid without extensive filtration (need 2.3).

Capacity of storage system is defined as the physical volume of the spill containment system. This criterion should carry less weight than others since the spill containment system should have a capacity that reflects the amount of fluid that is stored in the hydraulic loading room. The capacity should be sized appropriately so that frequent sources of spills are able to be contained.

System's ability to effectively collect fluid spills refers to how well the system can collect fluids. It is crucial that the proposed design can contain fluid spills consistently and systematically. Therefore, a system that reduces the amount of time spent cleaning fluid spills is highly desirable (need 2.1).

Mitigation of hazards to employees governs the system's ability to reduce the number of hazards to employees that are present in the hydraulic loading room. Common hazards in the hydraulic loading room include slips, trips, and chemical fumes caused by exposed chemicals. Therefore, the system should have the ability to eliminate slipping hazards and contain fluid spills safely to prevent irritation due to chemical inhalation (need 6).

Limits exposure to hydraulic fluid sensitive components means the spill containment system should prevent Skydrol LD-4-sensitive components from coming into contact with fluid spills. It is highly desirable for the spill containment system to prevent objects such as floor mats, walls, and glycol hoses from encountering Skydrol LD-4 (need 2.5).

Compatible with layout refers to how well the spill containment system accompanies the proposed hydraulic loading room layout. The spill containment system should be able to collect fluid spills without having any negative impacts on the layout of the equipment in the room. Our group decided to include this criterion to ensure that the spill containment system is compatible with the selected layout.

Does not impede ease of HLU installation refers to the ability of the spill containment system to be installed and implemented without introducing any additional inconveniences to the process required for installing the HLU in the hydraulic loading room. A system can be deemed desirable if there are no obstructions in the way of the HLU (need 1.1).

Ease of separating fluids refers to how well the system can collect fluid spills separately and simultaneously. Therefore, the system should be able to contain both hydraulic fluid and glycol spills in the event that both fluids are present at the same time (need 2.2).

Each of the aforementioned criteria were inserted into a criteria weighting matrix, as shown in Table B- IV, in order to determine an appropriate weight for each criterion.

TABLE B- IV: SPILL CONTAINMENT SYSTEM CRITERION WEIGHTING MATRIX

Spill Containment Criteria		**Cost of system**	**Ease of fluid drainage**	**Ease of cleaning spill containment system**	**Ability to retain fluid without contaminants**	**Capacity of storage system**	**System ability to effectively collect fluid ...**	**Mitigation of hazards to employees**	**Limits exposure to hydraulic fluid sensitive**	**Compatible with layout**	**Does not impede ease of HLU installation**	**Ease of separating fluids**
Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**K**	**L**
A	**Cost of system**		B	C	A	E	F	H	I	J	K	A
B	**Ease of fluid drainage**			B	B	B	F	H	I	B	K	B
C	**Ease of cleaning spill containment system**				C	C	F	H	I	J	K	C
D	**Ability to retain fluid without contaminants**					E	F	H	I	J	K	D
E	**Capacity of storage system**						F	H	I	J	K	E
F	**System's ability to effectively collect fluid spills**							H	F	F	K	F
H	**Mitigation of hazards to employees**								H	H	H	H
I	**Limits exposure to hydraulic fluid sensitive components**									I	I	I
J	**Compatible with layout**										K	L
K	**Does not impede ease of HLU installation**											K
L	**Ease of separating fluids**											
	Total Hits	2	6	4	1	3	8	10	8	4	8	1
	Weight	0.04	0.11	0.07	0.02	0.05	0.15	0.18	0.15	0.07	0.15	0.02

All the spill containment criteria and concepts were inserted into a weighted decision matrix in order to obtain a score for each design. These concepts were than ranked in accordance with the concept scores to determine which design was most applicable for our client's application. Decisions were made for each of the concept ratings based on the research that was conducted and the information provided in the Concept Generation section of this report. The results of this weighted decision matrix have been shown in Table B-V.

TABLE B-V: SPILL CONTAINMENT WEIGHTED DECISION MATRIX

Spill Containment		Concepts												
			Troughs under each connection point		Floor grate with gravity drain		Perforated floor gravity drains		Spill pallets		Drain by each equipment to a basin with sump		Garage barrier	
	Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Cost of system	0.036	5	0.182	3	0.109	2	0.073	4	0.145	1	0.036	5	0.182
B	Ease of fluid drainage	0.109	2	0.218	4	0.436	4	0.436	3	0.327	2	0.218	1	0.109
C	Ease of cleaning spill containment system	0.073	3	0.218	2	0.145	2	0.145	4	0.291	1	0.073	1	0.073
D	Ability to retain fluid without contaminants	0.018	3	0.055	1	0.018	1	0.018	3	0.055	1	0.018	1	0.018
E	Capacity of storage system	0.055	2	0.109	5	0.273	5	0.273	5	0.273	5	0.273	5	0.273
F	System's ability to effectively collect fluid spills	0.145	3	0.436	3	0.436	5	0.727	4	0.582	1	0.145	4	0.582
G	Mitigation of hazards to employees	0.182	2	0.364	2	0.364	2	0.364	5	0.909	2	0.364	1	0.182
H	Limits exposure to hydraulic fluid sensitive components	0.145	4	0.582	1	0.145	2	0.291	4	0.582	1	0.145	1	0.145
I	Compatible with layout	0.073	5	0.364	3	0.218	4	0.291	3	0.218	5	0.364	2	0.145
J	Does not impede ease of HLU installation	0.145	4	0.582	5	0.727	4	0.582	3	0.436	4	0.582	2	0.291
K	Ease of separating fluids	0.018	4	0.073	1	0.018	1	0.018	5	0.091	1	0.018	1	0.018
	Total Score			3.18		2.89		3.22		3.91		2.24		2.02
	Rank			3		4		2		1		5		6
	Continue?			No		No		Yes		Yes		No		No

As shown in Table B-V, the spill pallets concept received the highest score after our group analyzed the weights of each criterion for all six designs. This suggests that spill pallets are the most applicable design to implement in the hydraulic loading room and should therefore be pursued in the final report. To better support the choice of implementing spill pallets, our group has chosen to complete a more in-depth trade-off study between spill pallets and perforated floor grates in the final design report.

3.3. Heating System: Criteria and Design Selection Matrices

The criteria established by the team for the evaluation of the potential heating concepts is as follows:

Cost of heating system refers to the approximate monetary value of the system for comparison purposes. MDS AeroTest did not specify an exact budget thus was not an explicit need, however keeping costs low increases design appeal and likelihood of design implementation.

Maintains or improves air quality (does not re-vaporize hydraulic fluid) refers to the ability of the system to ensure that airborne levels of vaporized hydraulic fluid remains below threshold levels for extended worker exposure in accordance with the MSDS of Skydrol LD-4 [7] (need 4.1).

Ease of cleaning refers to how easy the system components would be to clean if the hydraulic fluid was to be spilled on the heating system (need 1.4).

Controllability of temperature refers to the ability of the heating system to be adjusted and set to a desired temperature (need 4.2).

Even temperature distribution refers to the ability of the heating system to disperse the heat evenly throughout the room (need 4).

Compatibility with ventilation system refers to the ability of the system to heat the room sufficiently as the ventilation system is operating (need 4).

Heating response time refers to the time it takes for the system to reach the desired set temperature (need 4.2).

Energy efficiency of system refers to how sustainable the heating system is and how well it saves energy. This selection criterion was not an explicit need from the client, however environmental sustainability is still important.

Durability of system refers to the system's expected lifespan when operating in the hazardous environment of the hydraulic loading room. It is also important for the system to function adequately in the cold climate of Thompson, MB. There was no explicit need for this selection criterion.

Compatibility with layout refers to optimization of the heating system placement within the layout (need 1).

Compatibility of materials with hydraulic fluid refers to the components in the heating system are not degraded by aviation grade hydraulic fluid (need 7).

Noise Level of the heating solution should not cause undue discomfort to operators working in the room without hearing protection post testing. The system chosen will score higher for lower noise emission however it will need to operate below 70dB [9] (need 6).

To identify the best heating concept from the concepts generated in Section 2.4, selection criteria were developed based on the requirements of the system for a successful final design. The selection criteria were then organized into a criterion weighting matrix to assign weights that gauge the importance of each to the final design. The selection criteria in the weighting matrix are shown in Table B-VI.

TABLE B-VI: HEATING SYSTEM CRITERION WEIGHTING MATRIX

Heating Criteria		Cost of heating system	Maintain/ improves air quality	Ease of cleaning	Controllability of temperature	Even temperature distribution	Compatibility with ventilation system	Heating response time	Energy efficiency of system	Durability of system	Fire retardant	Compatibility with layout	Compatibility of materials with hydraulic fluid	Noise level
Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**K**	**L**	**M**	**N**
A	Cost of heating system		B	C	D	E	F	G	H	I	K	L	M	A
B	Maintain/ improves air quality (does not re-vaporize hydraulic fluid)			B	B	B	B	B	B	B	K	B	B	B
C	Ease of cleaning				D	C	F	C	C	I	K	C	M	N
D	Controllability of temperature					D	D	D	D	D	K	L	M	D
E	Even temperature distribution						F	E	E	E	K	L	M	N
F	Compatibility with ventilation system							F	F	F	K	L	M	F
G	Heating response time								G	G	K	L	M	N
H	Energy efficiency of system									I	K	L	M	N
I	Durability of system										K	L	M	N
K	Fire retardant											K	K	K
L	Compatibility with layout												M	L
M	Compatibility of materials with hydraulic fluid													M
N	Noise level													
Total Hits		1	11	5	8	4	7	3	1	3	12	8	10	5
Weight		0.01	0.14	0.06	0.10	0.05	0.09	0.04	0.01	0.04	0.15	0.10	0.13	0.06

The team compared the importance of each selection criterion by comparing each one individually. This developed a weight of importance for each criterion. After setting weights to each of the selection criterion, each of the heating system concepts were ranked from 1 to 5 in how well that system concept satisfies the criteria. The rank is multiplied by the weight and summed to create an overall score. The scores for each system concept were compared and the top two highest scoring concepts were considered for the final selected design. The top scoring concept was not selected out right, since when all the different sub systems come together, the team wanted to have a few options in case the heating system was not compatible with the layout or another system. The scoring matrix is shown in Table B-VII.

TABLE B-VII: HEATING SYSTEM CONCEPT SCORING MATRIX

Heating			Concepts												
			Forced air heater - ceiling mounted		Radiant floor heating		Radiant wall heating		Infrared heater - ceiling mounted		Furnace heater		Panel radiator		
	Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	
A	Cost of system	0.01	3	0.038	2	0.026	2	0.026	5	0.064	2	0.026	4	0.051	
B	Maintains/ improves air quality	0.14	3	0.423	4	0.564	5	0.705	1	0.141	5	0.705	5	0.705	
C	Ease of cleaning	0.06	2	0.128	4	0.256	5	0.321	3	0.192	5	0.321	4	0.256	
D	Temperature control	0.10	4	0.410	3	0.308	4	0.410	4	0.410	5	0.513	5	0.513	
E	Even temperature distribution	0.05	2	0.103	3	0.154	4	0.205	3	0.154	5	0.256	4	0.205	
F	Compatibility with ventilation system	0.09	1	0.090	3	0.269	3	0.269	4	0.359	5	0.449	3	0.269	
G	Heating response time	0.04	4	0.154	2	0.077	3	0.115	4	0.154	5	0.192	4	0.154	
H	Energy efficiency of system	0.01	3	0.038	5	0.064	5	0.064	3	0.038	3	0.038	5	0.064	
I	Durability of system	0.04	3	0.115	5	0.192	5	0.192	4	0.154	5	0.192	4	0.154	
J	Fire retardant	0.15	4	0.615	5	0.769	5	0.769	2	0.308	5	0.769	5	0.769	
K	Compatibility with layout	0.10	5	0.513	5	0.513	5	0.513	5	0.513	3	0.308	4	0.410	
L	Compatibility of materials with hydraulic fluid	0.13	3	0.385	5	0.641	5	0.641	3	0.385	5	0.641	5	0.641	
M	Low noise level	0.06	3	0.192	5	0.321	5	0.321	5	0.321	4	0.256	5	0.321	
		Total Score		3.21		4.15		4.551		3.19		4.667		4.51	
		Rank		5		4		2		6		1		3	

From Table B-VII we observe that the furnace heating was the best concept for the hydraulic loading room application. This concept is considered the best option for the room, however if the furnace heater is too bulky for the room layout, or another unforeseen issue arises for this concept, the radiant heating is the next best option. During the final design phase, the type of furnace, the placement of the furnace and the supporting heating calculations will be fully developed to complete the final overall facility design.

3.4. Ventilation System

The criteria that the team developed to evaluate the viability of the ventilation system concepts is as follows:

Cost of ventilation system: Although a target budget was not provided, the team still acknowledges the financial investments that need to be made to implement this design. As a result, the relative cost of the ventilation system is included as one of the selection criteria.

Material compatibility: The components that are used in the ventilation system must be corrosion resistant to the environment that it is placed in. However, there may be some areas where the degradation of components is acceptable if a greater benefit to the air quality is realized (need 7.1).

Efficiency of ventilation system: Focuses on the energy efficiency of the system as well as the heat that is lost as a result of inefficiencies in the ventilation system.

Provides airflow to critical areas of room: The ventilation system will also be evaluated based on its ability to provide adequate airflow to areas of the room that people are expected to be working and the ventilation system's ability to remove contaminants from the air (need 5).

Standard deviation of hydraulic fluid retention time: This is a measure of the ventilation system's ability to remove all contaminants from the space. For example, even though a ventilation system may provide ten air changes per hour, particles residing in a relatively stagnant area of the room may only be changed once per hour, or possibly not at all (need 5).

Variable control of the system: The importance of having the ability to adjust the ventilation rate of the room is another consideration that the team presents. If the ventilation rate is adjustable, the amount of fresh air entering the space can be reduced when the air quality in the room is at, or better than, the required level in order to save on energy usage and heating costs (need 4.2).

Exhaust air away from walking & working areas: Exhausting air away from walking and working areas refers to being able to exhaust the contaminated air from the hydraulic loading room to an area where the exhaust of contaminated air will not affect workers in the surrounding area of the trailer. For example, this could mean exhausting the air from the roof of the building instead of on the side of the trailer to eliminate the discharge of air into a direct working path (need 5.3).

Compatibility with heating system: Compatibility of the ventilation system with the heating system was also considered. Ideally, the team wanted the heating and ventilation systems to work together to provide a comfortable solution to both climate control of the space as well as maintaining the required air quality in and around the room. This was not an explicit need but was considered as a functional system requirement.

Compatibility with layout: Lastly, how well the ventilation system integrates with the proposed layout of the hydraulic loading room needs to be considered. From this criterion, the team was looking to avoid bulky items that could get in the way of employees when they are working in the hydraulic loading room.

Table B-VIII shows the results of the comparison between the criteria presented in the weighted decision matrix. The number of wins that a certain criterion has, compared to the total wins possible provides the weights to be used in the ventilation weighted decision matrix. The matrix to establish these weights is seen in Table B-VIII.

TABLE B-VIII: VENTILATION WEIGHTED WEIGHTS DECISION MATRIX

Ventilation System Criteria		Cost of ventilation system	Material compatibility of ventilation components	Efficiency of ventilation system	Provides airflow to critical areas of room	Standard deviation of hydraulic fluid retention time	Variable control of the system	Exhaust air away from walking & working areas	Compatibility with heating system	Compatibility with layout
Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
A	Cost of ventilation system		B	C	D	E	F	G	A	I
B	Material compatibility of ventilation components			C	D	E	F	G	B	I
C	Efficiency of ventilation system				D	E	F	G	C	I
D	Provides airflow to critical areas of room					E	D	G	D	D
E	Standard deviation of hydraulic fluid retention time						F	G	E	E
F	Variable control of the system							G	F	F
G	Exhaust air away from walking & working areas								G	G
H	Compatibility with heating system									I
I	Compatibility with layout									
	Total Hits	1	2	3	6	6	6	8	0	4
	Weightings	0.03	0.06	0.08	0.17	0.17	0.17	0.22	0.00	0.11

The ventilation system weighting matrix provides the weights used in the concept scoring matrix. From the information provided, we see that the exhaust of air away from walking and working areas carries the greatest importance with 22% of the weight, followed by variable control of the system, the ability to provide airflow to critical areas of the room and the standard deviation of hydraulic fluid retention time all carrying 17% of the total weight.

The team then took the weights achieved in the criteria weighting matrix (for ventilation) and evaluated the five ventilation concepts against the criteria. The results are provided on the following page in Table B-IX.

TABLE B-IX: VENTILATION WEIGHTED DECISION MATRIX

Ventilation			Concepts									
			Dilution ventilation with forced-air heating		Local exhaust ventilation		Industrial fan		Dilution ventilation		Displacement ventilation	
	Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
A	Cost of ventilation system	0.0278	4	0.111	2	0.056	5	0.139	4	0.111	4	0.111
B	Material compatibility of ventilation components	0.0556	5	0.278	5	0.278	4	0.222	5	0.278	5	0.278
C	Efficiency of ventilation system	0.0833	5	0.417	5	0.417	1	0.083	5	0.417	5	0.417
D	Provides air flow to critical areas of room	0.167	5	0.833	5	0.833	2	0.333	5	0.833	5	0.833
E	Standard deviation of hydraulic fluid retention time is minimized	0.167	3	0.500	4	0.667	3	0.500	3	0.500	4	0.667
F	Variable control of the system	0.167	4	0.667	5	0.833	1	0.167	3	0.500	4	0.667
G	Exhaust of air away from walking areas	0.222	5	1.111	5	1.111	3	0.667	5	1.111	5	1.111
I	Compatibility with layout	0.111	4	0.444	2	0.222	1	0.111	4	0.444	1	0.111
	Total Score			4.36		4.42		2.22		4.20		4.20
	Rank			2		1		5		2		4
	Continue?			Yes		Yes		No		No		No

From Table B-IX the team concluded that local exhaust ventilation is the best option to provide ventilation to the hydraulic loading room. However, it is important to note that local exhaust ventilation requires air to be replaced in the room that the contaminated air was evacuated from. Thus, in order to improve the airflow patterns into the room the team has decided to implement dilution ventilation with the integrated heating system. This will also allow for greater temperature and ventilation control of the room. The team will evaluate the effectiveness of the dilution ventilation system in the final design phase of this project and decide at that time if local exhaust ventilation is required in addition to the dilution ventilation system based on the expected emission rate of tributyl phosphate as well as any other potentially harmful contaminants.

3.5. Facility Layout

To identify the optimal layout design from the five iterations displayed in Table B-I, a selection system had to be established. The team began by comparing the new designs against the current room configuration in all four criteria areas established in Section 2.1. Designs that improved on the current layout were assigned pluses, a tie was not assigned any value, and areas where utility was lost were assigned a negative value. The pluses and minuses were then tallied in order to eliminate designs that showed negligible improvement over the current room layout. This analysis is summarized in Table B-X.

TABLE B-X: PRELIMINARY LAYOUT SCREENING MATRIX

	Concept Variants					
Selection Criteria	A	B	C	D	E	Reference
Ease of installing HLU	+	+	+	+	+	0
Walkway square footage (unobstructed)	+	+	+	0	0	0
Hose organization	+	+	+	-	0	0
Ease of accessibility of equipment	+	+	+	+	+	0
Pluses	4	4	4	2	2	0
Nulls	0	0	0	1	0	0
Minuses	0	0	0	1	2	0
Net	4	4	4	1	0	
Continue?	Yes	Yes	Yes	No	No	

From Table B-X we see that a three-way tie occurred between concepts A, B, and C, which showed improvements over the current design in four categories. Designs D and E showed one or no areas of improvement respectfully. Since the latter two layout configurations did not show improvements that would set them apart from the first three designs, we chose to eliminate them from further screening. With the knowledge that the room layout would likely be a design similar to configuration A, B, or C, we then began assessment of heating, ventilation, spill containment and prevention systems that would likely function in those environments. To conduct a second round of screening, we decided to include two new layout criteria in addition to the four outlined in Section 2.1. The two added criteria are as follows:

HVAC system compatibility: The chosen heating and ventilation system(s) should not have its function or installation impeded by the equipment layout plan.

Spill containment and prevention system compatibility: The selected spill containment and containment system(s) should not have their function or installation impeded by the equipment layout plan

The addition of these criteria was done to ensure final layout compatibility with the heating, ventilation, spill containment and prevention systems selected. The complete list of all six layout selection criteria can be seen in Table B- XI. This table serves to compare the selection criteria and assign weights corresponding to their importance.

TABLE B- XI: WEIGHTED WEIGHTS DECISION MATRIX

Layout		Ease of installing HLU	Walkway square footage	Hose organization	HVAC compatibility	Spill system compatibility	Ease of accessibility
Criteria		**A**	**B**	**C**	**D**	**E**	**F**
A	Ease of installing HLU		A	A	A	A	A
B	Walkway square footage			C	B	E	F
C	Hose organization				D	E	C
D	HVAC compatibility					E	F
E	spill system compatibility						E
F	Ease of accessibility						
	Total Hits	5	1	2	1	4	2
	Weightings	0.33	0.07	0.13	0.07	0.27	0.13

Layout designs A, B, and C were screened against the six criteria and assigned ratings out of five, wherein one was considered poor and five was considered ideal. These ratings could then be multiplied by the criteria weights generated in Table B- XI. The results of this screening analysis are seen in Table B-XII.

TABLE B-XII: FINAL LAYOUT SCREENING MATRIX

Hydraulic Loading Room Layout		**Concepts**						
			A		B		C	
Selection Criteria		**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
A	Ease of installing HLU	0.333	3	1.000	5	1.667	5	1.667
B	Walkway Square Footage	0.067	5	0.333	4	0.267	3	0.200
C	Hose Organization	0.133	5	0.667	4	0.533	4	0.533
D	HVAC System Compatibility	0.067	4	0.267	5	0.333	4	0.267
E	Spill collection/prevention compatibility	0.267	4	1.067	5	1.333	4	1.067
F	Ease of Maintenance of Equipment	0.133	4	0.533	4	0.533	5	0.667
		Total Score		3.9		4.7		4.4
		Rank		3		1		2
		Continue?		No		Yes		No

Table B-XII shows us that layout concept B ranked highest in terms of the six criteria outlined and will thus be pursued as our final design.

4. References

[1] J. Johnson, "Open-center valves in mobile equipment," Hydrualics and Pneumatics, 8 April 2009. [Online]. Available: https://www.hydraulicspneumatics.com/200/TechZone/HydraulicValves/Article/False/84094/TechZone-HydraulicValves. [Accessed 20 October 2019].

[2] MDS AeroTest, "Conceptual Design of Hydraulic Loading Room Layout and HVAC," Thompson, MB, 2019.

[3] ULINE, "Spill Containment Pallets," Image Accessed: October 2019. [Online]. Available: https://www.uline.ca/BL_8211/Spill-Containment-Pallets.

[4] Western Sling, "Ultratech Garage Barrier (American Made)," Image Accessed: October 2019. [Online]. Available: https://westernsling.com/ultratech-garage-barrier-american-made/sku/.

[5] Ultratech International Inc., "Garage Barriers," [Online]. Available: https://www.spillcontainment.com/products/garage-barriers/. [Accessed 20 October 2019].

[6] Solutia Inc., "Skydrol Type IV Fire Resistant Hydraulic Fluids LD-4 / 500B-4: Technical Bulletin," Solutia Inc., St. Louis, MO, 2003.

[7] Eastman Chemical Company, "Safety Data Sheet for Skydrol LD4 Fire Resistant Hydraulic Fluid," 06 02 2015. [Online]. Available: https://www.eastman.com/Brands/EAS/Skydrol/Pages/Product.aspx?pid=71093409 . [Accessed 09 October 2019].

[8] Price Industries Ltd., "Displacement Ventilation Engineering Guide," 2018. [Online]. Available: https://www.priceindustries.com/content/uploads/assets/literature/engineering-guides/displacement-ventilation-engineering-guide.pdf. [Accessed 23 October 2019].

[9] U. D. o. H. a. H. Services, "Too Loud. Too Long," 28 May 2019. [Online]. Available: https://www.noisyplanet.nidcd.nih.gov/parents/too-loud-too-long. [Accessed 23 October 2019].

C. Appendix – Gantt Chart

		Task Name	Planned Start Date	Planned Finish Date	Percent Complete
1		**1.0 Phase 1 - Planning**	9/12/2019	12/8/2019	100 %
2		1.1 Develop Risk Register	9/12/2019	9/16/2019	100 %
3		1.2 Assess and Mitigate Risks	9/16/2019	12/8/2019	100 %
4		1.3 Develop Stakeholder Register	9/12/2019	9/16/2019	100 %
5		1.4 Develop Schedule and Gantt Chart	9/12/2019	9/16/2019	100 %
6		**2.0 Phase 2 - Define Project**	9/17/2019	10/9/2019	100 %
7		2.1 Establish Site Visit Questions and Preliminary Needs	9/17/2019	9/18/2019	100 %
8		2.2 MDS AeroTest Site Visit	9/19/2019	9/19/2019	100 %
9		2.3 Establish Project Needs	9/20/2019	9/21/2019	100 %
10		2.4 Establish Target Specifications	9/22/2019	9/23/2019	100 %
11		2.5 Work on Project Definition Report	9/20/2019	9/25/2019	100 %
12		2.6 Project Definition Report Internal Deadline	9/26/2019	9/26/2019	100 %
13		2.7 Prepare Oral Presentation	9/27/2019	10/3/2019	100 %
14		2.8 Project Definition Report Edit	9/27/2019	9/29/2019	100 %
15		2.9 Project Definition Report Due	9/30/2019	9/30/2019	100 %
16		2.10 Send Project Definition Report and Client Evaluation Form to Client	9/30/2019	9/30/2019	100 %
17		2.11 Oral Presentation Due	10/4/2019	10/4/2019	100 %
18		2.12 Peer Evaluations Due	10/4/2019	10/4/2019	100 %
19		2.13 Gantt Chart and Meeting Minutes Due	10/9/2019	10/9/2019	100 %
20		**3.0 Phase 3 - Conceptual Design Development**	10/1/2019	10/30/2019	100 %
21		**3.1 Research**	10/1/2019	10/4/2019	100 %
22		3.1.1 Research Chemicals Used	10/1/2019	10/4/2019	100 %
23		3.1.2 Research Ventilation Systems	10/1/2019	10/4/2019	100 %
24		3.1.3 Research Spill Containment Systems	10/1/2019	10/4/2019	100 %
25		3.1.4 Research Heating Systems	10/1/2019	10/4/2019	100 %
26		3.1.5 Research Mobile Room Options	10/1/2019	10/4/2019	100 %
27		3.1.6 Research Applicable Policies and Standards	10/1/2019	10/4/2019	100 %
28		3.1.7 Research Valves and Other Spill Prevention Methods	10/1/2019	10/4/2019	100 %
29		3.2 Work on Concept Design Report	10/5/2019	10/20/2019	100 %
30		3.3 Generate Concepts	10/5/2019	10/12/2019	100 %
31		3.4 Concept Analysis	10/13/2019	10/18/2019	100 %
32		3.5 Concept Selection	10/19/2019	10/20/2019	100 %
33		3.6 Concept Design Report Internal Deadline	10/21/2019	10/21/2019	100 %
34		3.7 Concept Design Report Edit	10/22/2019	10/24/2019	100 %
35		3.8 Concept Design Report Due	10/25/2019	10/25/2019	100 %
36		3.9 Send Concept Design Report and Client Evaluation Form to Client	10/25/2019	10/25/2019	100 %
37		3.10 Peer Evaluations Due	10/26/2019	10/26/2019	100 %
38		3.11 Gantt Chart and Meeting Minutes Due	10/30/2019	10/30/2019	100 %
39		**4.0 Phase 4 - Final Design**	10/28/2019	12/6/2019	100 %
40		4.1 Optimize and Finalize Selected Conceptual Design	10/28/2019	11/15/2019	100 %
41		4.2 Develop Conceptual Engineering Drawings	11/7/2019	11/15/2019	100 %
42		4.3 Develop Final Estimated Budget	11/18/2019	11/19/2019	100 %
43		4.4 Work on Final Design Report	11/1/2019	11/24/2019	100 %
44		4.6 Invite Client to Final Presentation Evening	11/18/2019	11/18/2019	100 %
45		4.7 Final Design Report Draft Due	11/25/2019	11/25/2019	100 %
46		4.4 Prepare Poster for Final Presentation	11/26/2019	12/3/2019	100 %
47		4.8 Gantt Chart and Meeting Minutes Due	11/27/2019	11/27/2019	100 %
48		4.9 Final Design Report Edit	11/26/2019	12/3/2019	100 %
49		4.10 Final Report and Poster Due	12/4/2019	12/4/2019	100 %
50		4.11 Send Final Design Report and Client Evaluation Form to Client	12/4/2019	12/4/2019	100 %
51		4.12 Final Presentation	12/5/2019	12/5/2019	100 %
52		4.13 Peer Evaluation 3 Due	12/6/2019	12/6/2019	100 %